ENVIRONMENTAL MONITORING PROGRAM WATER QUALITY MONITORING ELEMENT REVIEW AND RECOMMENDATIONS

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I. Introduction

The San Francisco Estuary is managed to provide diverse –and in some cases competing– beneficial uses. For example, waters flowing into the estuary are a source for municipal, industrial, and agricultural consumption, yet these same waters also receive point- and nonpoint-source discharges of pollutants. The estuary also provides essential habitat and migration pathways for a multitude of aquatic organisms, including several native species of concern and species of commercial and recreational value. Ongoing information on water quality conditions is fundamental to the near- and long-term management of the estuary and preservation of its beneficial uses.

The CA Department of Water Resources and US Bureau of Reclamation have responsibility for an Environmental Monitoring Program (EMP) that monitors water quality conditions in the upper estuary. Data from the EMP are used to assess estuary conditions in relation to beneficial uses, which are listed as water quality objectives in the Bay-Delta Water Quality Control Plan (SWRCB 1995). These data are also used to document status and trends in environmental conditions throughout the upper estuary and in models used to predict future conditions.

This document describes a recommended monitoring program for the water quality element of the EMP based on identified needs, and our understanding of the hydrodynamic processes driving environmental conditions in the estuary. The geographic scope of this program includes the Sacramento-San Joaquin Delta, and Suisun and San Pablo bays. Collectively, these areas are referred to as the "upper estuary." Water quality monitoring in other areas of the San Francisco Estuary (e.g., Central and South bays) are considered mainly in terms of opportunities for coordination with other programs.

For the purpose of this document, water quality refers to the basic physical and chemical attributes of water as they affect the beneficial uses and environmental conditions of the upper San Francisco Estuary. Monitoring of contaminants (e.g., pesticides and heavy metals) is not addressed as an integral part of the recommended program, but the general issue of contaminants monitoring is considered. With the exception of organic carbon, this document does not address water quality monitoring as it pertains to drinking water (e.g., pathogens, Trihalomethane formation potential, arsenic concentrations, etc).

II. Conceptual model

The conceptual model[1] for water quality is based on the premise that the hydrology of the upper watersheds and fundamental hydrodynamic transport processes, such as advection and dispersion, control much of the temporal and spatial variability in water quality conditions of the upper estuary. Thus, to adequately monitor status and trends in water quality variables, the EMP sampling design must take into account the inherent variability in time and space imposed by these processes. Of greatest interest to the EMP are the longer-term trends in the measured variables, most notably seasonal and yearly trends. Yet, to detect seasonal-to-yearly changes in these variables it may be necessary to collect data at shorter time scales, when much of the temporal variability is thought to occur. In the San Francisco Estuary, much of the temporal variability is associated with the tidal time scale, which varies over periods of about 12 and 24 hours, and the spring/neap time scale, which varies with a period of about 14 days.

Tidal currents are responsible for much of the tidal time scale variability in water quality conditions at any particular location in the upper estuary. This is because substantial along-estuary spatial gradients exist in most water quality variables. As the tidal currents advect these spatial gradients past a sampling location, the gradients register as temporal variations in the water quality time series at each sampling location. Although the strength of the tidal currents diminishes with distance from the Pacific Ocean, much of the variability in these currents, at most points in the estuary, is at the tidal time scale. The net or residual flows usually account for a small fraction of the temporal variability in the tidal currents. Therefore, for most of the water quality variables measured by the EMP variations in time and space are not independent, rather changes in time and space are intimately connected through the tidal currents.

The tidal currents, river inflows, water project exports, temporary channel barriers, and delta cross-channel gate operations all contribute to transport within the upper estuary and thus, all contribute to spatial and temporal variability in water quality conditions.[2] The tidal currents dominate transport processes throughout the estuary (Figure 1), except in the upland fringes of the delta and during periods of large uncontrolled run-off events (floods). The tidal currents are not under direct human control, except through significant changes to the geometry of the system. River inflows can introduce the greatest seasonal signal in water quality variables measured by the EMP and have the greatest impact during periods when they are outside human control – during the late-winter/early-spring uncontrolled run-off events. Yet river inflows at low to

[1] Much of the information presented in this conceptual model is based on information presented in Monismith and others, 1998.
[2] Hereafter water project exports, temporary channel barriers, and delta cross-channel gate operations are collectively referred to as “project operations.”

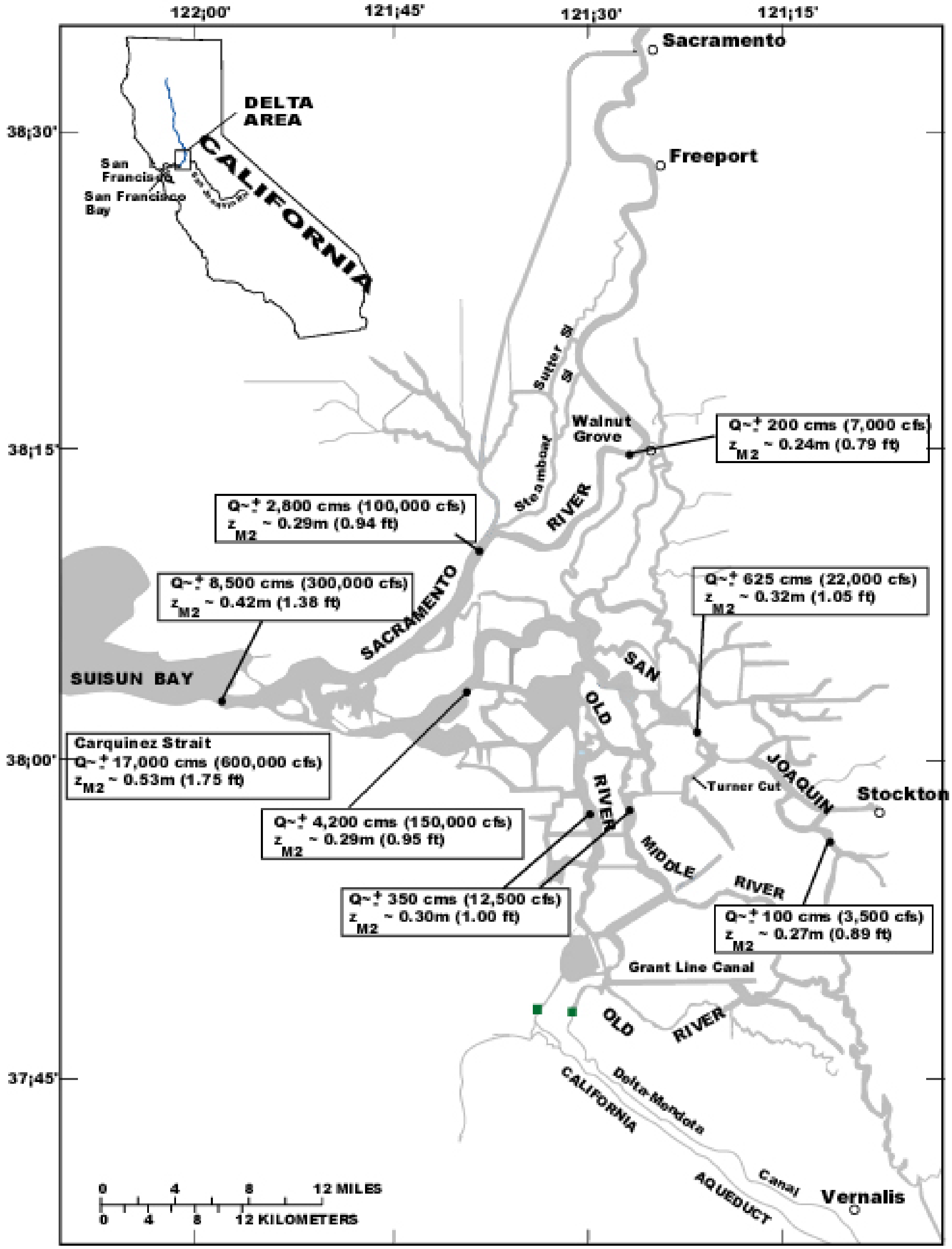


Figure 1. Spatial variations in tidal forcing throughout the upper estuary where Q is the tidal discharge, or flow, and z_{M2} are the sea level variations due to the principal semi-diurnal, M2, partial tide.

moderate levels and project operations are under human control. The control of river flows for project operations directly connect the operation of California's water supply systems to valuable ecosystem processes and functions, most notably entrainment losses and X2-abundance relations (Jassby and others, 1995).[3]

The recommended EMP design for monitoring water quality considers tidal processes acting on three distinct time scales: daily, fortnightly, and seasonal. The water quality conditions in the upper estuary are largely a consequence of the hydrologic and transport processes acting on these time scales, as well as locally distinct and regional sources of spatial variability. The remainder of this section contains a more detailed discussion of the sources of temporal and spatial variability most affecting transport and water quality.

A. Temporal variability

<u>Tidal time scale (ca. 1 day)</u>. Tidal currents, driven by tide-generated sea level variations at the Golden Gate Bridge, (Figure 2) dominate transport in the upper estuary. The tidal currents are on the order of 1 m/s in the Bay (Figure 3) and western delta and thus the tidal currents can transport a given water parcel roughly 20 kilometers (i.e., the tidal excursion) over a single tidal cycle (~ 6 hours). Significant along-channel spatial gradients in water quality variables advected by the tidal currents create large temporal variations in time-series measured at fixed locations. For example, in Figure 4, salinity, salinity stratification, and suspended solids concentrations are shown to significantly vary on the tidal timescale. Power spectral density (PSD) estimates (Marple, 1987, Stearns and David, 1988) are useful in quantifying temporal variability in time series. Figure 5 shows a PSD estimate computed based on the data given in Figure 2. On the logarithmic scale given, it is clear most of the variability in sea level at the Presidio occurs at roughly 12 and 24 hours. Tidal timescale sea level variations drive tidal timescale variations in the currents as well (Figure 6). The temporal variability in the currents, in turn, affect transported quantities such as salinity, which also vary mostly at the tidal timescale (Figure 7).

The interaction between variations in tidal currents and spatial heterogeneity results in a number of physical processes that also affect water quality. These processes include dispersive exchange, lateral shear, vertical mixing, water column stratification, and turbulent mixing. On tidal time scales, passive organisms and chemical constituents can be moved back and forth between a shallow shoal to a deeper channel or from one river system to another. For example, tidal time scale transport from the Sacramento River to the San Joaquin occurs through Threemile Slough and through Sherman Lake. These are examples of dispersive exchange that generally occur when the local tidal excursion is greater than the length of the connecting channel. Lateral shears in

[3] X2 is defined as the distance (in kilometers) from the Golden Gate Bridge of the 2 PSU bottom salinity.

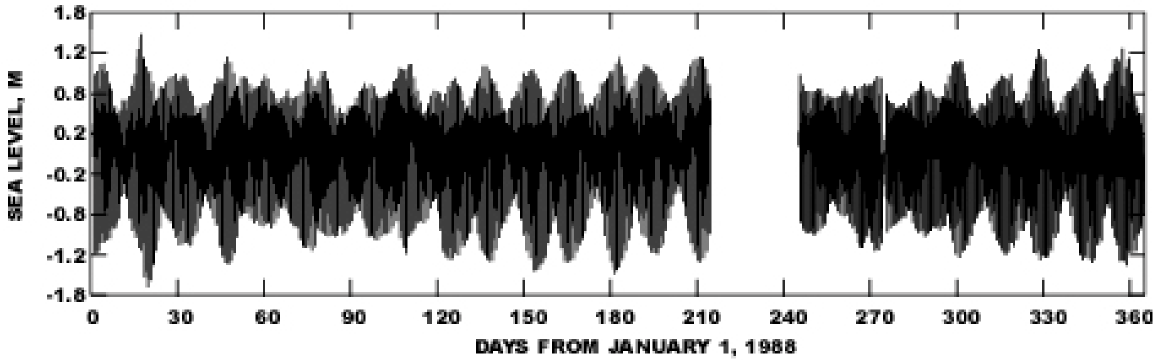


Figure 2. Time series plot of sea level measured at the Presidio near the Golden Gate Bridge.

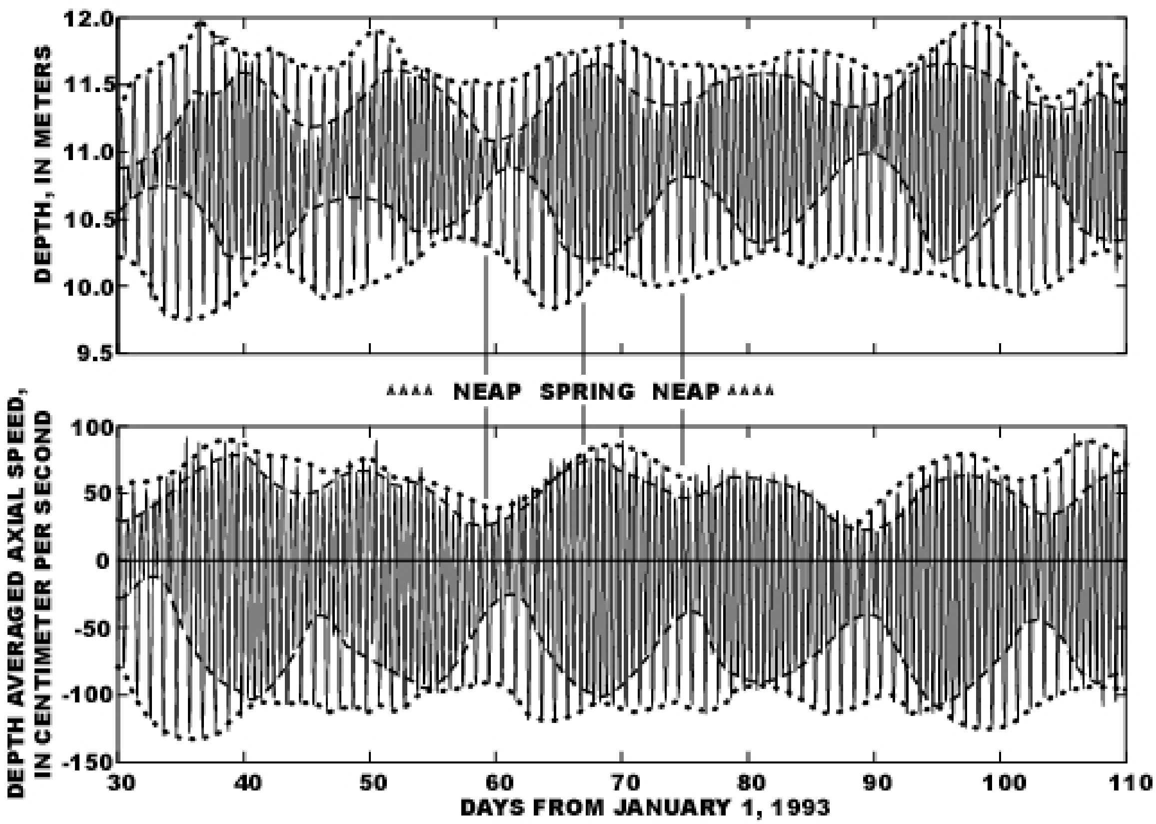


Figure 3. Time series plots of (top) depth and (bottom) depth averaged axial (or along-channel) speed measured near Bulls Head in Suisun Bay. Tidal timescale sea level variations drive strong tidal currents at Bulls head, in this example, and throughout the estuary.

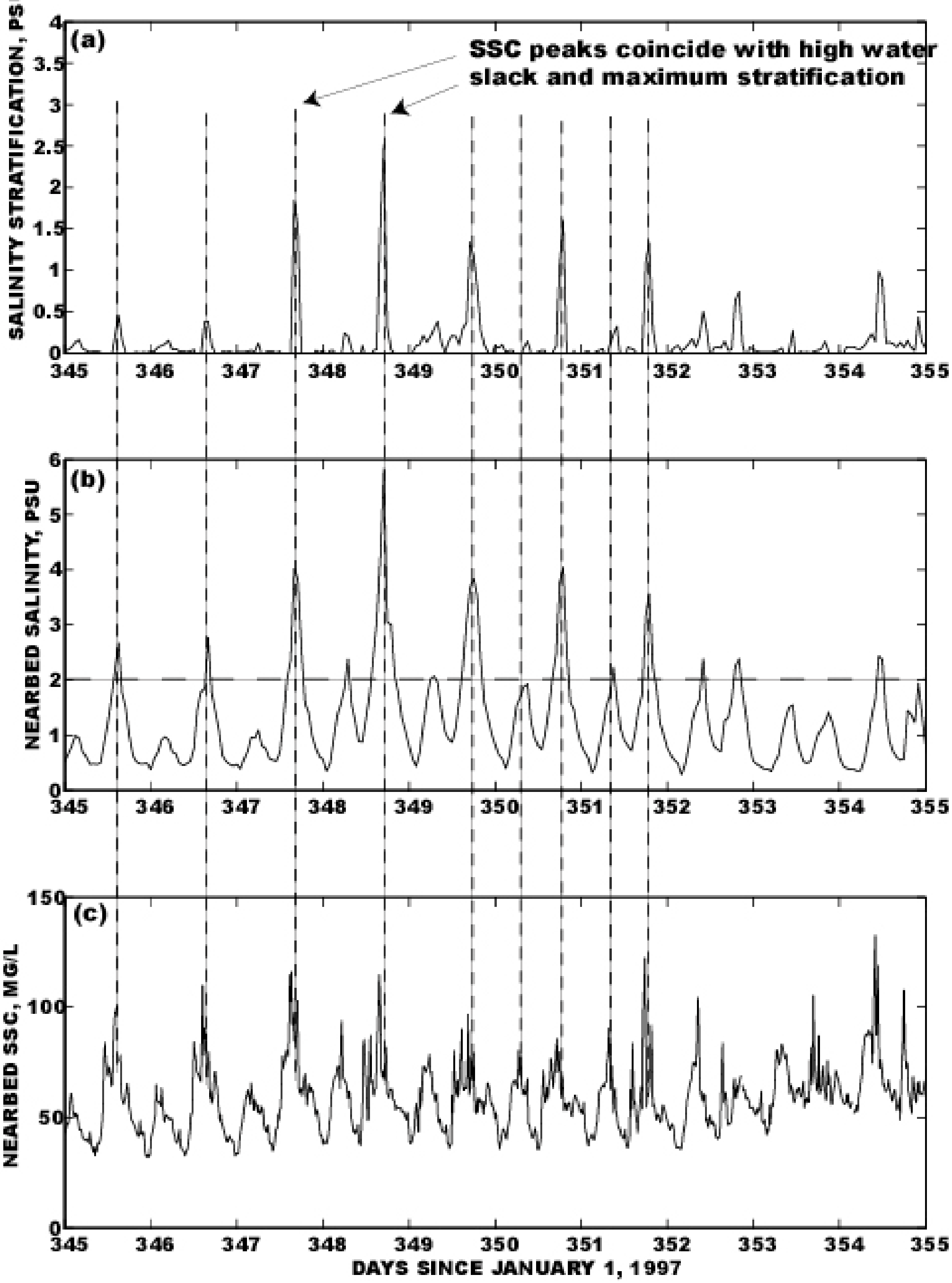


Figure 4. Time series plots of (A) salinity stratification, (B) salinity, (C) near-bed suspended solids concentration (SSC) measured at Mallard Island. In an advection-dominated system, such as San Francisco Bay estuary, high water slack (slack after flood) coincides with the maximum salinity measured at a point. Thus, the vertical dashed lines drawn through the salinity peaks correspond to the time of high water slack. In this example, the periods of maximum stratification and peak SSC occur at high water slack.

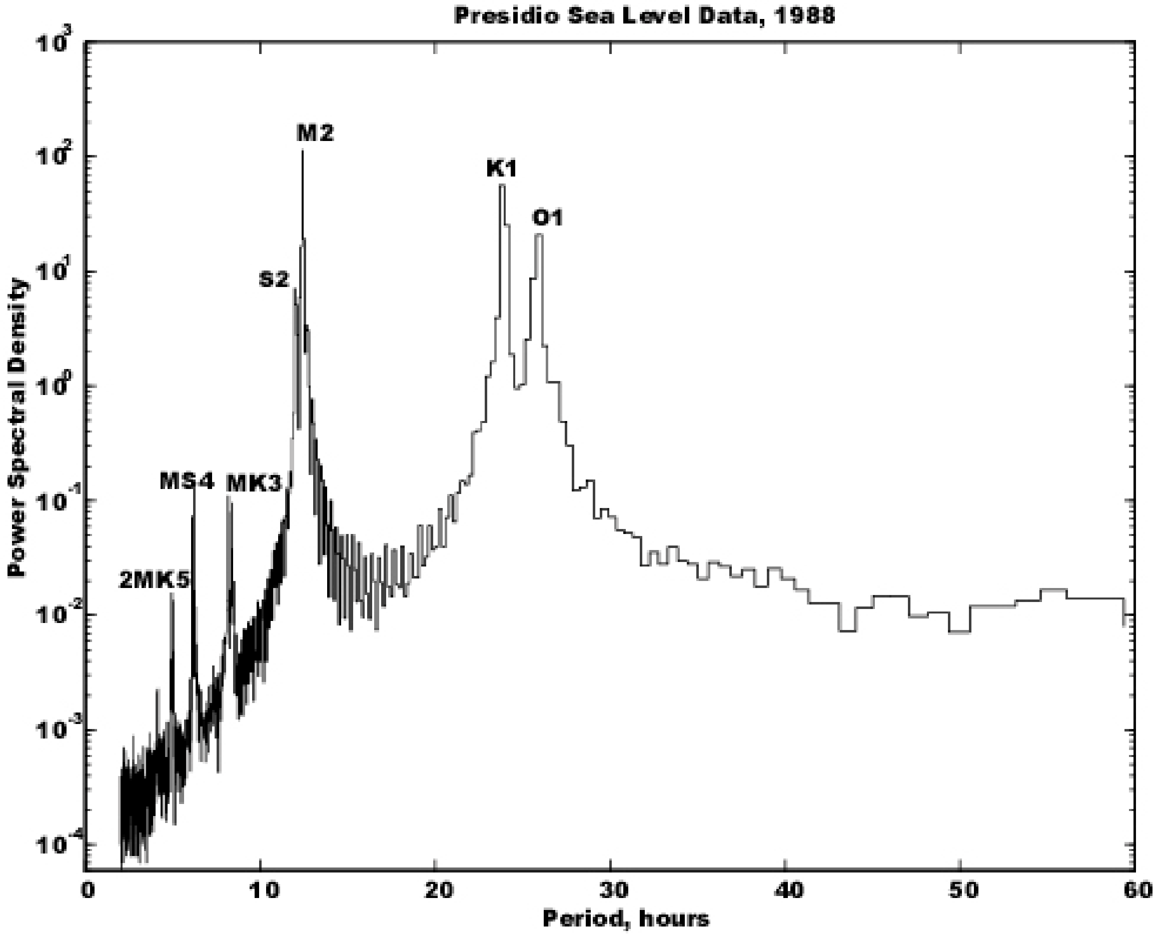


Figure 5. Power Spectral Density obtained from sea level data collected at the Presidio tide gauge in 1988. Several partial tides are shown (from right to left): diurnal constituents: O1, K1; semi-diurnal constituents: M2, S2; and three non-linear (harmonic) modes: MK3, MS4, 2MK5.

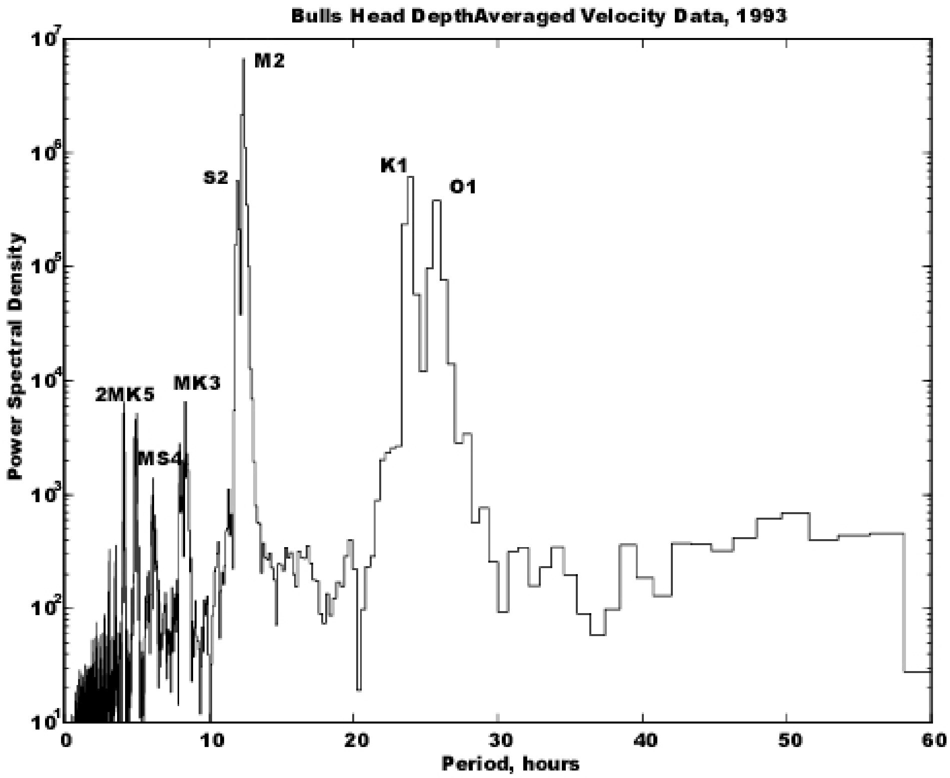


Figure 6. Power Spectral Density obtained from vertically averaged acoustic Doppler current profiler (ADCP) data collected near Bulls Head in Suisun Bay in 1993. Several partial tides are shown (from right to left): diurnal constituents: O1, K1; semi-diurnal constituents: M2, S2; and three non-linear (harmonic) modes: MK3, MS4, 2MK5.

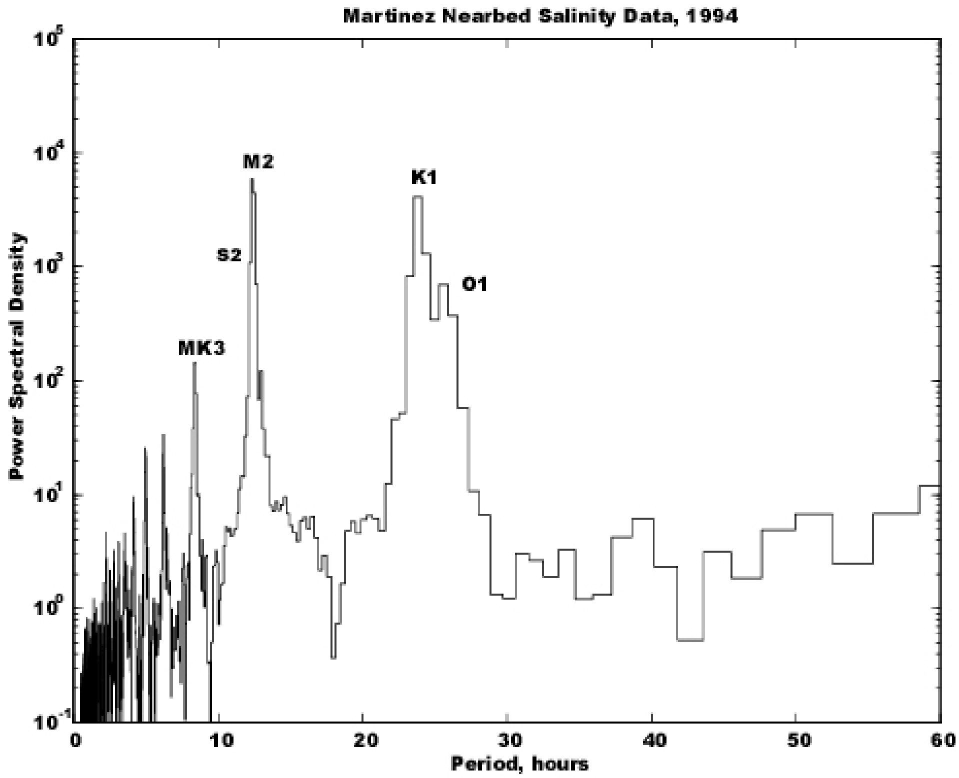


Figure 7. Power Spectral Density obtained from near-bed salinity time series data collected at the Martinez shore station in 1994. Several partial tides are shown (from right to left): diurnal constituents: O1, K1; semi-diurnal constituents: M2, S2; and three non-linear (harmonic) mode: MK3.

tidal currents caused by depth variations and channel curvature can lead to rapid dispersion on the tidal time scale. In the delta, flow splitting at channel junctions can also lead to rapid dispersion of materials throughout the delta on the tidal time scale. Tides also control vertical mixing and through sediment resuspension, the light field and the presence of particles upon which some chemical transformations, perhaps mediated by microbes, may take place. Density stratification of the water column (Figures 4 and 8) and thus, gravitational circulation strength can also vary on the tidal time scale due to variations in turbulent mixing.

Diurnal winds patterns is another factor of regional importance acting on the tidal time scale (~24 hours), although not a direct function of the tides. Diurnal winds typical to the region can generate wind-induced current and surface wave field variations at diurnal time scales. The interactions between wind and water lead to diurnal variations in suspended sediment concentrations, but may also affect localized surface salinity levels, which can be critical to compliance with delta salinity standards.

<u>Fortnightly spring-neap cycles</u>. Residual circulation patterns, water levels, salinity intrusion, and mean sediment concentration are all strongly modulated by spring-neap tidal variations (Figure 9). For example, during periods of low river flows, subtidal flows associated with filling (spring tide) and draining (neap tide) of the delta (with stage changing by as much as 0.3 m) can be quite important. These subtidal flows can lead to net flow into the delta at times when the mean water balance (e.g., DAYFLOW calculation) for the delta indicates the opposite condition.

Subtidal variations in flows and chemical and particle concentrations are responsible for much of the net movement of material through the system. For example, fortnightly variations in bottom stress and thus sediment re-suspension create fortnightly variations in suspended sediment concentrations (SSC), where SSC is greatest during spring tides (Figure 9b) when bottom stress is greatest. Thus, an important conceptual distinction between mean flows and tidal flows is that tidal motions generally cause a cloud of particles (e.g., fish eggs) to disperse, whereas it is the rectified effects of tides, including mean discharge, that cause net movement of the cloud centroid. An important subtlety for transport is that net movement of the cloud is not only determined by the residual Eulerian current field (what is measured by an array of current meters), but also by the phasing and spatial variations of tidal currents.

Besides residual currents due to river inflow and those created by tidal variations in bottom stress, a principal contributor to net (subtidal) transport downstream of X2 is gravitational circulation.[4] Indeed, the Entrapment Zone theory that guided

[4] Gravitational circulation is defined as water circulation caused by the interaction of water parcels of different density. In coastal estuaries, gravitational circulation arises from the interaction of ocean water and river water.

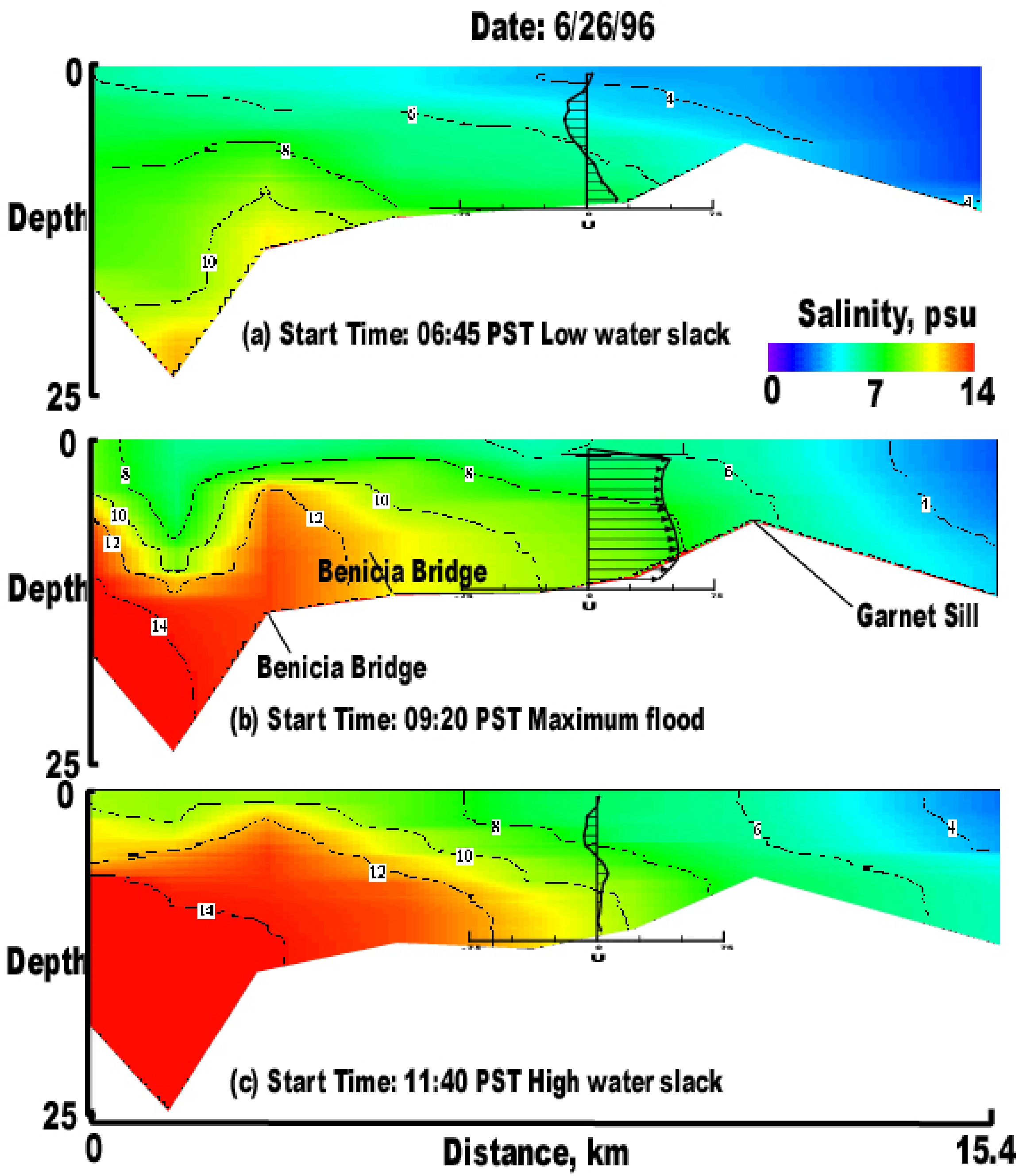


Figure 8. Interpolated cross-sectional views of the reserve fleet channel in Suisun Bay interpolated from 8 conductivity-temperature-depth (CTD) profiles. Each transect (or “snapshot”) took approximately 30 minutes. Velocity profiles from an upward-looking acoustic Doppler current profiler (ADCP) are shown in the approximate location of the ADCP within the transect.

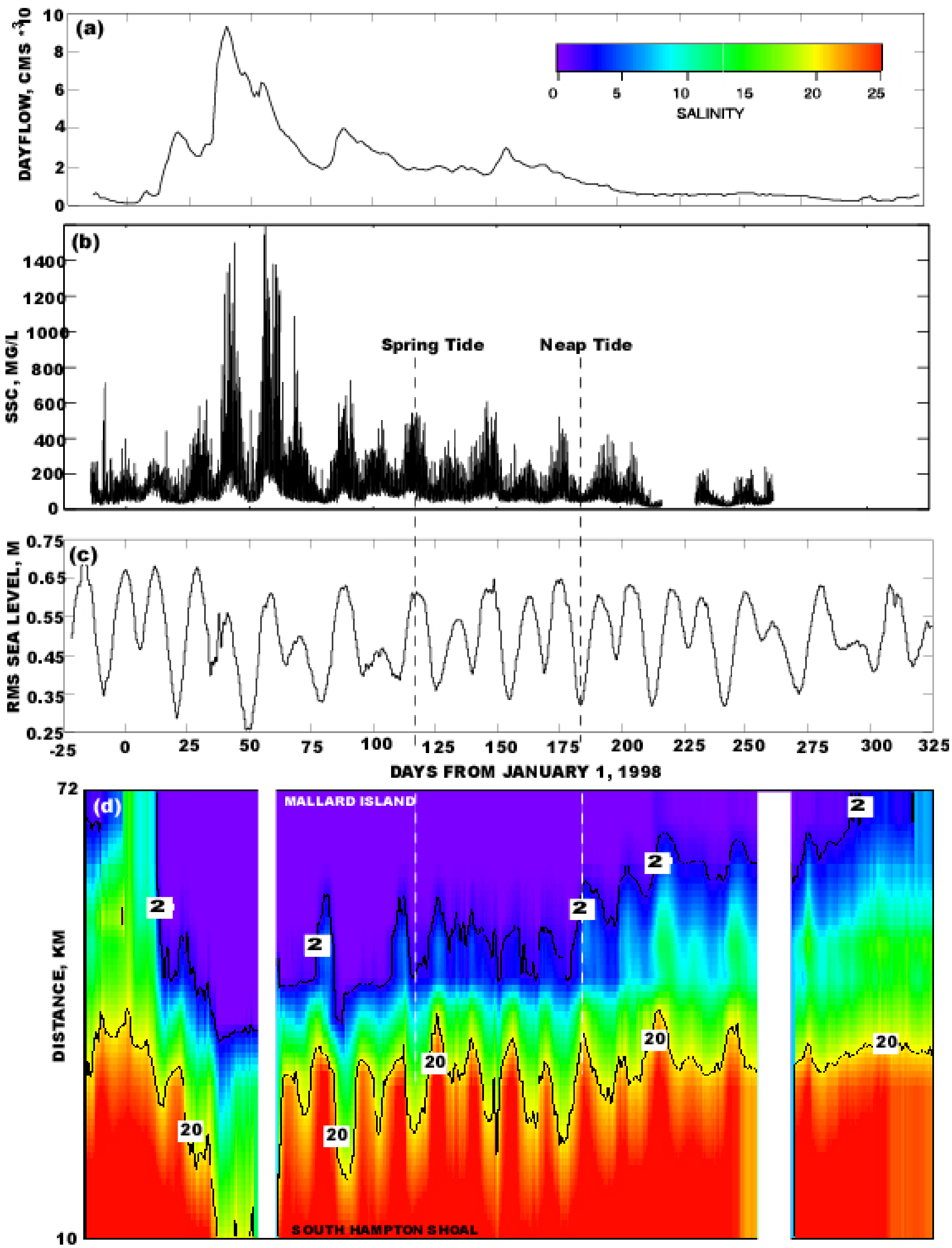


Figure 9. Time series plots of (a) DAYFLOW, (b) suspended solids concentration (SSC) measured at Martinez, (c) root-mean-square (RMS) sea level measured at the Presidio, (d) the axial near-bed salt field interpolated from 12 conductivity-temperature-depth (CTD) sensors arrayed along the axis of the estuary from South Hampton Shoal to Mallard Island.

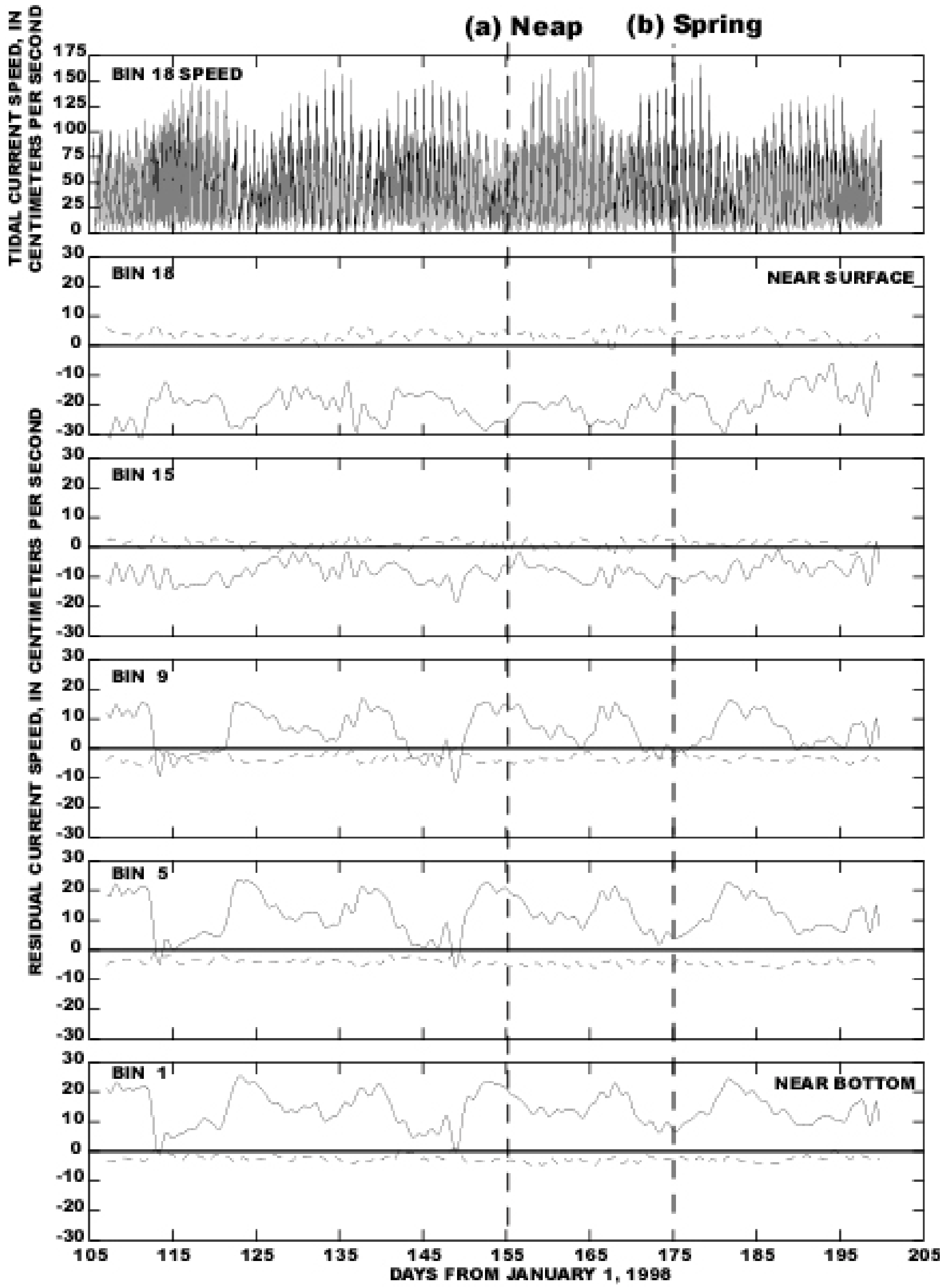


Figure 10. Time series of tidally-averaged ADCP data measured at the Richmond Bridge where the solid line shows the along-channel velocity component and dashed line shows the transverse component. Bin-1 is the near-bottom measurement and Bin-18 is the near-surface measurement. Gravitational circulation at this location is modulated by the spring/neap cycle where typical profiles (at the vertical dashed lines) are shown in Figure 11.

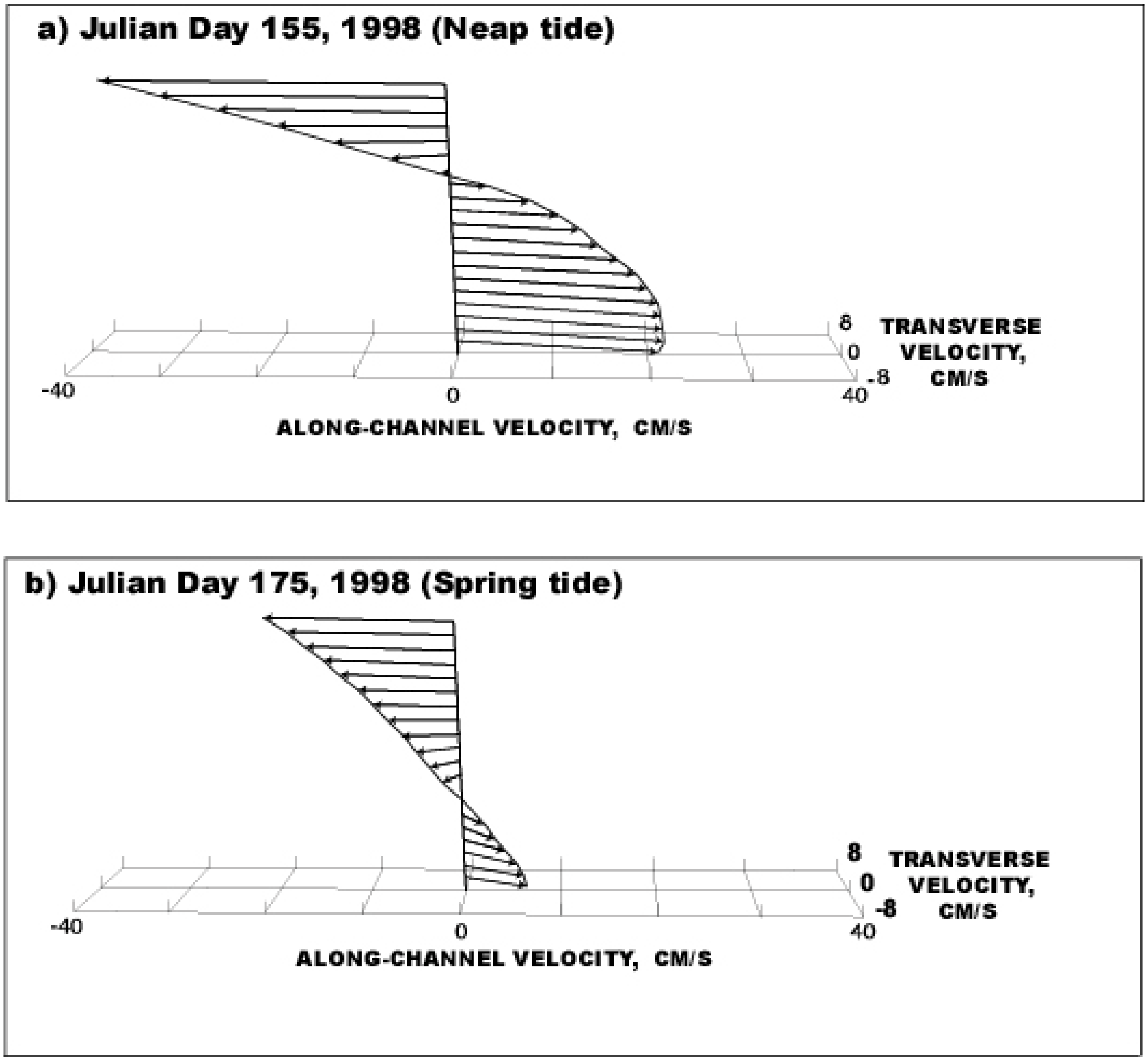


Figure 11. Typical vertical profiles in water velocity measured at the Richmond Bridge, which show gravitational circulation (bi-directional flow) is strongest on neap tides.

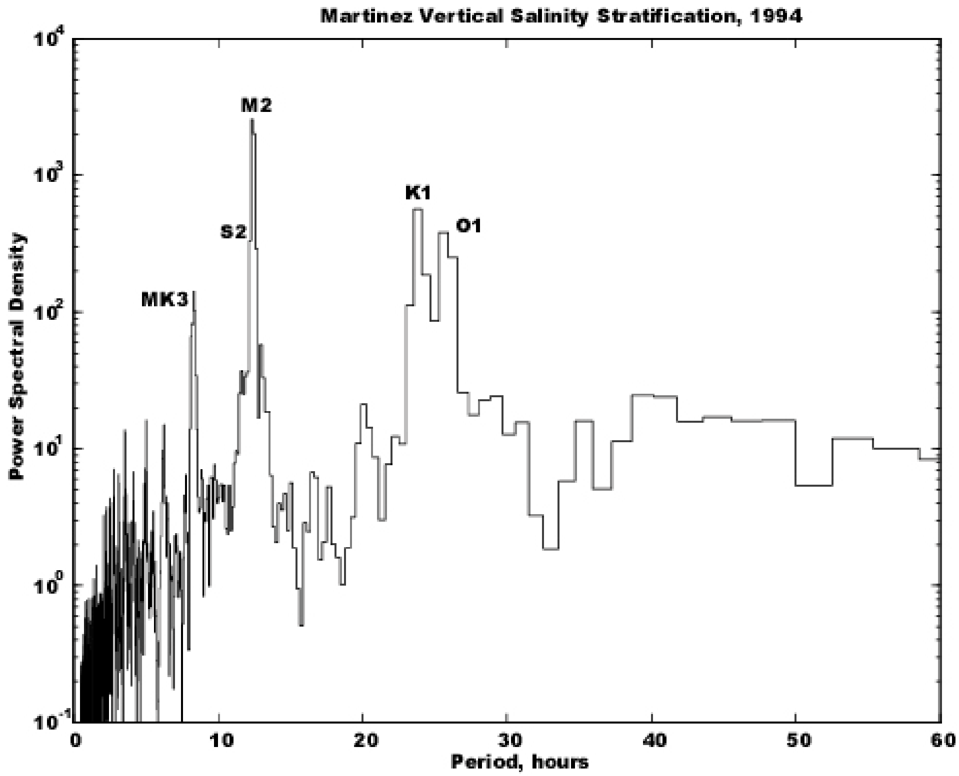


Figure 12. Power Spectral Density obtained from salinity stratification (top sensor minus bottom sensor) time series collected at the Martinez shore station in 1994. Several partial tides are shown (from right to left): diurnal constituents: O1, K1; semi-diurnal constituents: M2, S2; and one non-linear (harmonic) mode: MK3.

much IEP work for the last 25 years is largely based on a conceptual model of transport that only involves gravitational circulation. Not surprisingly, gravitational circulation is strongly modulated by spring-neap variations in tidal mixing (Figures 10 and 11). The spring/neap modulations in gravitational circulation result in fortnightly shifts in the tidally-averaged salt field (Figure 9d). Intensification of gravitational circulation at neap tides and with relatively small values of X2 appears associated with intensification of tidally varying stratification, which greatly reduces the frictional resistance of the water column to the pressure gradient associated with the longitudinal salinity gradient. Figure 12 shows that most of the temporal variability in stratification occurs at the tidal timescale. However, the tidal time scale variability in stratification is modulated by the spring/neap tidal cycle. During spring tides, turbulent tidal mixing dominates and little stratification develops. During neap tides, when turbulent mixing is weaker, density stratification can persist through the entire tidal cycle and can intensify over several tidal cycles. Thus, transitions between stratified and periodically stratified water columns accompany spring-neap variations as well as changes in outflow. In fact, it appears that these transitions are more strongly controlled by tides than by freshwater flow throughout most of the year. This condition illustrates the strong connection between tidal and subtidal variability.

Finally, to a first approximation, it takes roughly two weeks for changes in river flow to change the salinity field. This is based on the X2-Q relation given in Kimmerer and Monismith (1992) that connects X2 on a given day to both flow and X2 the previous day. This time scale is not what one would observe were mean advection to dominate, but may be indicative of the importance of dispersive salt fluxes to the overall salt balance, and the way those fluxes may depend on the strength of the longitudinal salinity gradient. This may also apply to the distribution of other chemicals.

Seasonal and annual cycles (and beyond). Seasonal variations in river flows (Figure 9a), project operations, and tides (solstices versus equinoxes) lead to variations in advective and dispersive processes in the upper estuary, and thus at first order, variations in the salinity field (i.e., variations in X2). Variations in X2 (Figure 9d) in turn lead to variations in the intensity and timing of gravitational circulation and hence of whatever net transport is supported by gravitational circulation. Driven by variations in sediment supply and in prevailing winds (summer versus winter), sediment deposition/erosion and transport also vary on the yearly time scale (Figure 9b). Sediment supply may be largely the result of a few intense runoff episodes (i.e., floods). Integration of these annual variations in sediment behavior over several years is what produces changes in bathymetry. Nutrient concentrations and transport likely mirror sediment dynamics to some degree. Although influenced by seasonal runoff, nutrient supplies are also influenced by anthropogenic activities (e.g., agricultural practices).

Overall then, a central challenge to collecting meaningful water quality data is to monitor at time scales that are relevant to the underlying transport processes which control the physical state of the upper estuary. These time scales vary over several orders of magnitude; thus requiring sampling at a variety of time scales using multiple approaches.

B. Spatial variability

Transport and mixing processes and their effect on water quality also vary along the axis of the system. In the eastern delta and upstream, net, or tidally averaged, flows dominate. Dispersion mechanisms are relatively well known in systems where the net flows dominate, although the effects of secondary flows that develop due to channel curvature and in channel junctions can complicate matters. In the western delta and downstream towards the ocean, tides are more important, especially during dry (low outflow) conditions (Figure 1). At the same time, mean advection due to river flow is generally lessened because channel cross-sections are larger than in the rivers. Besides the straightforward difference between riverine and tidal motions, other spatial differences include:

- The complex morphometry of the delta may greatly enhance longitudinal dispersion over what would be expected for the relatively prismatic channel sections of the delta. In particular, it is likely that splitting of tidal flows as they pass through the multiplicity of channel junctions typical of the delta is a main contributor to dispersion in the delta. Particular topographic features like the shallows on the western side of Franks Tract or the set of openings to the main channels that exist for Sherman Lake also may be locally important.
- In Suisun Bay, three main flow paths: the shipping channel, the combination of Suisun cutoff and the Reserve Fleet channel, and Montezuma Slough coexist with shallow-water regions like Middle Ground and Roe Island. These bathymetric features provide the flow path variability needed to support tidally based longitudinal dispersion of water, sediment, and other water quality variables.
- The large shallow (<2m MLLW) regions of the delta, Suisun and San Pablo bays are expected to have very different water residence times compared to the deeper channels because the tidal energy rapidly dissipates as the tidal wave moves from narrow channel to wide shallow regions. Large shallow areas are also expected to have very different sediment dynamics compared to the deeper channels because wind waves greatly enhance sediment resuspension in shallow regions over that experienced in the channels.
- One of the biggest sources of spatial variation is not fixed to any particular location. The longitudinal salinity structure gives rise to a mean baroclinic pressure gradient (i.e., variation in salt concentration) that supports gravitational circulation downstream of X2. Upstream of X2, the pressure

gradients that drive fluid motions are only due to variations in water surface elevation (barotropic pressure gradient). Since surface pressure gradients affect the entire water column in the same way, little vertical current shear is observed upstream of X2. Downstream of X2 the shear, especially as seen in tidally averaged velocities (Figure 12) and in instantaneous velocities around slack water, can be quite strong. Thus, spatial variations in hydrodynamic processes mediated by variations in the salt field (Figure 9d) directly affect longitudinal and vertical chemical concentrations.

- When the mean flow toward the ocean is sufficiently weak, net mean upstream flow can be observed at the bottom. It is this pattern that underlies the Entrapment Zone (EZ; a.k.a. Estuarine Turbidity Maximum, ETM) model. However, this picture neglects the complex bathymetry of Suisun Bay and the western delta, where the two dimensional mean flow structure required by the EZ/ETM model is not likely to be observed, and, as seen in computations only, tidal dispersion may be strong. It also does not account for the dynamic nature of stratification, particularly its intensification at neap tides.
- The various intertidal marshes and subtidal vegetated wetlands have altogether different physics from other habitat types in the upper estuary. Marshes are regions of very high bottom roughness (with plants often emerging through the water surface), and hence flows there are dominated by friction. Variations in plant density can lead to variations in friction that may be important for mean circulation, mixing and dispersion. There are also complex channel networks. Intertidal and shallow subtidal wetlands have received the least amount of attention as a habitat type sampled as part of the EMP. There is no doubt hydrodynamic processes affect water quality in these habitats, but the interactions among the biota, atmosphere, and land are expected to play a bigger role in overall water quality.

C. Linkages

Hydrodynamic processes dominate the environmental conditions in the upper estuary, and thus affect many aspects of the ecology. Direct connections are generally stronger with water quality, the lowest trophic levels, and the interactions among them. Particular linkages we consider strongest and most obvious include:

- X2-biota relations: A number of the postulated mechanisms for X2 dependence of species abundance have physical underpinnings. For example, recruitment of *Crangon fransiscorum* may depend upon transport mechanisms such as gravitational circulation, or may depend upon dynamics of the low salinity zone (Jassby and others, 1995).

- Wetlands: Hydrodynamic and sedimentary processes are thought to be fundamental determinants of the physicochemical character of wetlands, both in terms of defining current conditions and in influencing the creation of suitable habitat via restoration.
- Contaminants: Contaminant geochemistry is tied to both transport and sediment dynamics.
- System productivity: As stated above, interactions among lower trophic levels are regulated by physical processes both directly and indirectly through the resulting water quality conditions. For example, the regulation of primary production by benthic grazing is strongly influenced by the presence or absence of stratification (Koseff and others, 1993). Primary production can also be controlled by the length of time phytoplankton cells remain in regions conducive to growth, e.g., shallows or the photic zone in the channel. Finally, the importance to the overall food web of microbial processing of organic matter input into Suisun Bay may well be determined by the residence time of organic particles in Suisun Bay (Hollibaugh, 1996)
- Water Clarity: At seasonal scales, water clarity in the delta is primarily controlled by suspended material transported downstream from the upper watershed during large uncontrolled run-off events. Thus, water clarity is intimately tied to the hydrologic cycle. This pulse of sediment is temporarily stored in the system, primarily in shallow areas, and reworked and redistributed by wind waves and the tidal currents throughout the year. Algal blooms are also seasonal events dependent in part on residence time. Algal blooms can affect water clarity, particularly during warmer months.
- Geomorphology: The geomorphology of the system has been highly modified by anthropogenic activities. These modifications have generally increased the amount and extent of channels, reduced seasonal wetland habitat, and hardened the edges between water and land. However, geomorphologic changes still occur primarily from annual interactions between the wintertime large net flows, strong tidal currents, sediment supply (both bed load and suspended material), and bank protection. Changes in geomorphology can occur over long periods of time, such as sedimentation in levee-breached islands (examples include Sherman Lake, Big Break, Frank's Tract, and Mildred Island), or can occur as episodic events, such as during large floods. The geomorphology of the delta strongly influences transport and mixing processes and thus, over time, can influence variables of interest to the EMP. For example, creation of shallow water habitat may increase temperatures in delta waters to the point where eutrification could become a concern.

III. Customer oriented program evaluation

Customer needs were evaluated through direct discussions and review of written information. Several customers were contacted (e.g., agency staff, water users, academic researchers, and members of the public) to verify existing needs, to determine the level of satisfaction with the existing EMP water quality monitoring element, and to identify future needs. Results of this evaluation identified three specific and one general need (Table 1). Although the EMP meets some needs well, other needs are unmet and there is concern for the continued value of the overall program (see for example, Jassby and others, 2001). Several future needs were also identified that mainly depend on improvements or expansion in continuous monitoring or the integration of continuous water quality and water flow monitoring. These needs and concerns are used as a basis for recommended changes to the water quality-monitoring element.

IV. Prioritized recommendations for the water quality monitoring element

The EMP water quality element relies on three basic data collection techniques: 1) A network of continuous monitoring stations[5] distributed at shore locations throughout the upper estuary that report data on a 15-minute or hourly interval; 2) A discrete monitoring program that collects samples at established locations approximately once a month by boat or van; and 3) monthly discrete vertical profiles and continuous horizontal profiles of basic water quality conditions collected by boat. Each of these techniques has its advantages and disadvantages.

The continuous monitoring network has the advantage of temporal resolution, which means these data will not be aliased by tidal and spring/neap cycle variability. However, the continuous monitoring stations are located at the side of the channel (i.e., shore-based stations) to permit permanent installations and ready access. These shore-based stations facilitate instrument maintenance and operation and allow structures that protect against vandalism. However, data collected at the side of the channel may not represent conditions across the channel when strong vertical or lateral variability exists. Strong vertical variability occurs primarily seaward of X2, where salinity stratification can be important, and in areas where the tidal currents are weak and temperature stratification can occur, such as in flooded islands or in back sloughs. Lateral variability can be an issue in the wider portions of the system: in San Pablo and in Suisun bays, Carquinez Strait, the western delta, and in flooded islands, or in channels where

[5] The term “continuous monitoring station” is used throughout this document to denote a fixed location where water quality data is collected on a continuous basis using automated equipment. Continuous monitoring stations proposed in this document may be “in-situ” where the sensors and associated instruments are located at sample depth, or “shore-based” where the sensors and associated instruments are located on shore and sample water is brought to the sensors through a pump.

there are significant localized bathymetric features, such as a sand bar or a deep hole.

Discrete sampling by boat allows the collection of water samples from the middle of the channel or in the center of a broad shallow region, away from the influences of the shore where lateral variability is likely greatest. Boat-mounted continuous monitoring instrumentation also permits continuous horizontal and discrete vertical profiles of the water body to capture data on lateral and vertical variability. Thus, boat sampling is particularly appropriate where lateral or vertical variability is important. Boat mobility and access also increases sampling flexibility, which is very important in special studies. However, boats are expensive to maintain and operate, especially if the boat is underutilized.

Discrete sampling by van is the most limited sampling technique used in the EMP. Accessing sites by van limits sampling to the shore in most cases, although the center channel may be accessed from bridges at the some locations. Discrete sampling from shore or bridges limits the sampling techniques and precludes vertical profiling of the water column. Yet sampling by van does allow access to remote locations. In general, discrete sampling by boat or van does not provide the temporal resolution of continuous monitoring, but can allow access to more representative or remote waters. The water quality-monitoring program recommended in this document seeks to optimize the tradeoffs between continuous and discrete sampling methodologies.

Quite justifiably, a premium is placed on the prediction of system behavior. Interest ranges from current predictions of salinity and transport useful to guiding project operations, to long-term evaluations of water supply availability given the need to meet environmental (salinity, flow, and/or temperature) constraints in the face of year-to-year hydrologic variations. These interests will continue to exert influence on the design of the EMP water quality-monitoring element.

Issues and recommendations for the water quality element of the EMP are grouped as: 1) general considerations; 2) issues specific to downstream of X2; and 3) issues specific to upstream of X2. X2 is used as a boundary line throughout this document, because of the fundamental differences in hydrodynamic processes upstream and downstream of X2. The issues and recommendations presented below are based on the conceptual model and customer needs described above. Section VI provides a synthesis of the recommendations in the form of a proposed monitoring plan for water quality.

A. General considerations

There are several general considerations and recommendations that apply to the entire EMP water quality element. These issues are listed in order of priority in terms of their consideration in developing recommendations for program changes.

- *Representativeness.* The EMP should collect data that "best" represents the local area where the measurements are made. In general, the issue of representativeness is a consideration with all the issues and recommendations presented in this report. However, the issue of representativeness is specifically considered here in relation to the discrete vertical and continuous horizontal profiles conducted during boat-based sampling events. Examination of past vertical profile data from select sites (Appendix A) shows vertical variability exists within the water column in many parts of the estuary. This variation does not exhibit obvious seasonal or annual patterns. As described in the conceptual model, temporal variability at the tidal timescale is a substantial source of variability affecting water quality conditions throughout the water column. Thus, the "snapshot" of water quality conditions presented in the vertical profiles is highly transient, confounding our ability to elucidate underlying patterns or changes as a result of specific events.. Additionally, we have found that collection, processing, and management of the data generated from these vertical profiles comes at a relatively high cost of staff time. As a result, we recommend the EMP discontinue the routine collection of vertical water quality profiles, reserving the use of this instrumentation for special studies where intensive vertical profiling can provide a more robust picture of water column conditions through the tidal cycle. In contract, we recommend the EMP continue collection of boat-based horizontal profiles. These profiles provide a more complete "snapshot" of water quality conditions because spatially oriented data are collected continuously throughout the monitoring run. These data also require much less effort to collect, since the instrumentation operates independent of other data collection efforts. The EMP does need to invest in the development of data interpretation software that would allow web-based, graphical display of the horizontal profile data.

- *Continuity.* Any changes in the design of the EMP must carefully consider the historical water quality database. Changes in site locations and/or sampling frequency should minimize the degree to which historical data sets become "orphans." Special studies aimed at comparing data from one location to another or one analytical method to another should be considered where appropriate to minimize the loss of database continuity.

- *Data management.* A data management system should be designed to efficiently transform data into information. This system would include both quality assurance and rapid dissemination components.

- *Continuous and discrete sampling.* Continuous monitoring takes into account tidal aliasing and is amenable to a greater range of analytical techniques. Thus, in general we recommend establishing continuous monitoring stations for physical and chemical variables (e.g., conductivity, water temperature, pH, dissolved oxygen, turbidity, and fluorescence) supplemented by discrete sampling. Establishment of telemetry or modem capabilities for the continuous data should occur at key locations to facilitate timely data availability. Discrete monitoring will continue to play an important role in the water quality-monitoring element because reliable monitoring of some constituents (e.g., macronutrients or dissolved solids) can only occur through discrete sampling. In addition, discrete measurements of variables that are monitored continuously at the same locations are an important form of quality control.

- *Discrete sampling periods.* In those cases where discrete sampling is appropriate, discrete monitoring should be conducted in a manner that reduces biases associated with spring-neap cycle or fortnightly period (~14 day) variability. To avoid spring/neap cycle aliasing, sampling at even multiples of 14 days should be avoided and sampling at odd intervals in the spring/neap cycle should be encouraged. In essence, discrete sampling should be tied to the spring/neap cycle and not to a fixed monthly interval. Ideally, discrete sampling should alternate between the spring and neap tides.

- *Estimate fluxes.* Concurrent continuous monitoring of water flow (total discharge and/or velocity) should occur at key locations to permit calculations of fluxes for various constituents.

- *Tidal cycle aliasing.* Tidal cycle aliasing also can occur in discrete data, particularly in regions where temporal variability at tidal time scales is on the order of the seasonal time scale variability. The EMP has historically addressed tidal time scale variability by sampling at a fixed phase of the tide – high water slack. Since certain portions of the estuary can look very different depending on tidal current phase, sampling at a particular phase of the tide biases our view of the estuary to this tidal phase. The biases associated with sampling at a particular tidal current phase should be investigated using existing time series data. Moreover, the boats used for discrete sampling travel at half the tide wave propagation speed of ~20 knots. This means that on a given sampling run, which takes ~10 hours, not all samples can be collected at high water slack. This introduces another form of aliasing into the discrete data because the sampling vessel cannot keep up with the tide wave propagation speed. The effect of the “slow boat” should also be investigated. Specifically, a special study is needed that compares the measurements of samples collected from the San Carlos to measurements collected from a boat able to keep up with the tide. Comparative measurements should be made at least once per season for one year. The reality of operating a vessel in the public waterways of the delta is another factor that must be considered as part of this study. It may be that no boat is able to reach sampling stations in the delta at the same point on the tide.

- *Characterize water column structure.* Since a primary utility of shipboard sampling is its ability to measure vertical structure, we recommend the continued use of submersible instrumentation with conductivity, temperature, fluorometric, and optical backscatter sensors. Vertical profiles for monitoring purposes should be limited to regions of the estuary where vertical variability in these constituents exists.

- *Incorporate new techniques.* New techniques for sampling and analysis are continually becoming available. The EMP must be managed to allow for the evaluation and incorporation of new techniques as they prove their utility. Remote sensing is one example. Satellites now exist that can provide information at useful resolution in terms of pixel size and wavelength. Remote sensing for chlorophyll and turbidity concentrations, and for water temperature may be feasible (and are being tested in a pilot study at the Romberg Tiburon Center), and would provide vastly improved resolution of the spatial field of these key variables. Remote sensing can provide synoptic information over a broader geographic area, which could be helpful in the placement of monitoring stations. A feasibility study should be considered to investigate the value of adding a remote sensing component to the EMP. Use of existing work (e.g., the Romberg Tiburon Center pilot study) and alternative sources of funding (e.g., CALFED Science Program) should be investigated. Other examples of new technology include in situ water quality sensors and acoustic modems. These instruments could dramatically increase the locations and habitat types in which reliable water quality data can be collected on a continuous basis.

- *Expand analysis and information.* The EMP needs to investigate additional ways of relating water quality conditions to other environmental factors and biotic resources. Staff within the program may be able to do some of this work or make the data available in ways that facilitates such analyses by others. Some initial investigations include: 1) relate land use to water quality data. Using GIS, the EMP could evaluate land use information generated by other entities and relate this information to the water quality data it collects. 2) Water quality data should be more directly related to phytoplankton, zooplankton, and benthic monitoring data to better understand trends and changes. And 3) EMP data should be available to allow others to relate water quality conditions to the timing and location of fish spawning. For example, what were the water quality conditions at the time of striped bass spawning in the San Joaquin River? How did water quality conditions vary with the distribution of larval delta smelt, tracked through the 20 mm survey?

B. Issues and Recommendations for Water Quality Monitoring Downstream of X2 (Point San Quenten to Chipp's Island)

The waters of San Pablo and Suisun bays are often horizontally (laterally) and vertically heterogeneous in the water quality variables of interest to the EMP. This spatial variability makes it difficult to obtain water quality data that is "representative" of the cross-section (local area) where it is measured.

As described in the conceptual model, lateral and vertical variability present challenges to collecting "representative" data. For example, researchers using data collected at the Martinez continuous monitoring station must assume these data generally represent conditions in this area of Carquinez Strait (Figure 13). Yet results from more detailed sampling and modeling suggest the data collected at the Martinez station (located on the side of the channel) may not represent conditions in the center of the channel, or the cross section as a whole (Figure 14). Data collected at the Martinez station are used as boundary conditions in numerical models (DWR, 2000). These models are used to study salinity intrusion into the delta under a variety of hydrologic conditions, ultimately to aid in forecasting water project operations and in planning studies. The numerical models used by the agencies are one-dimensional and thus, to be consistent with their formulations, they require cross-sectionally averaged quantities as input boundary conditions. The output of these models would likely improve if the data used to generate the cross-sectional averages were collected from the center of the channel at several depths.

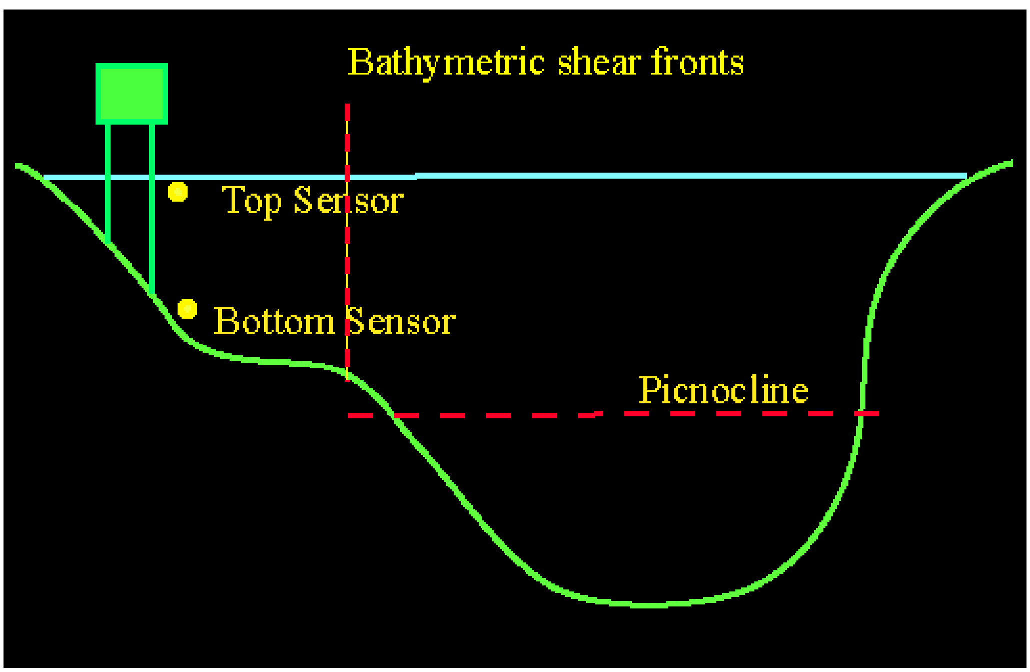


Figure 13. Schematic cross section of Carquinez Strait at the Martinez shore-based continuous monitoring station.

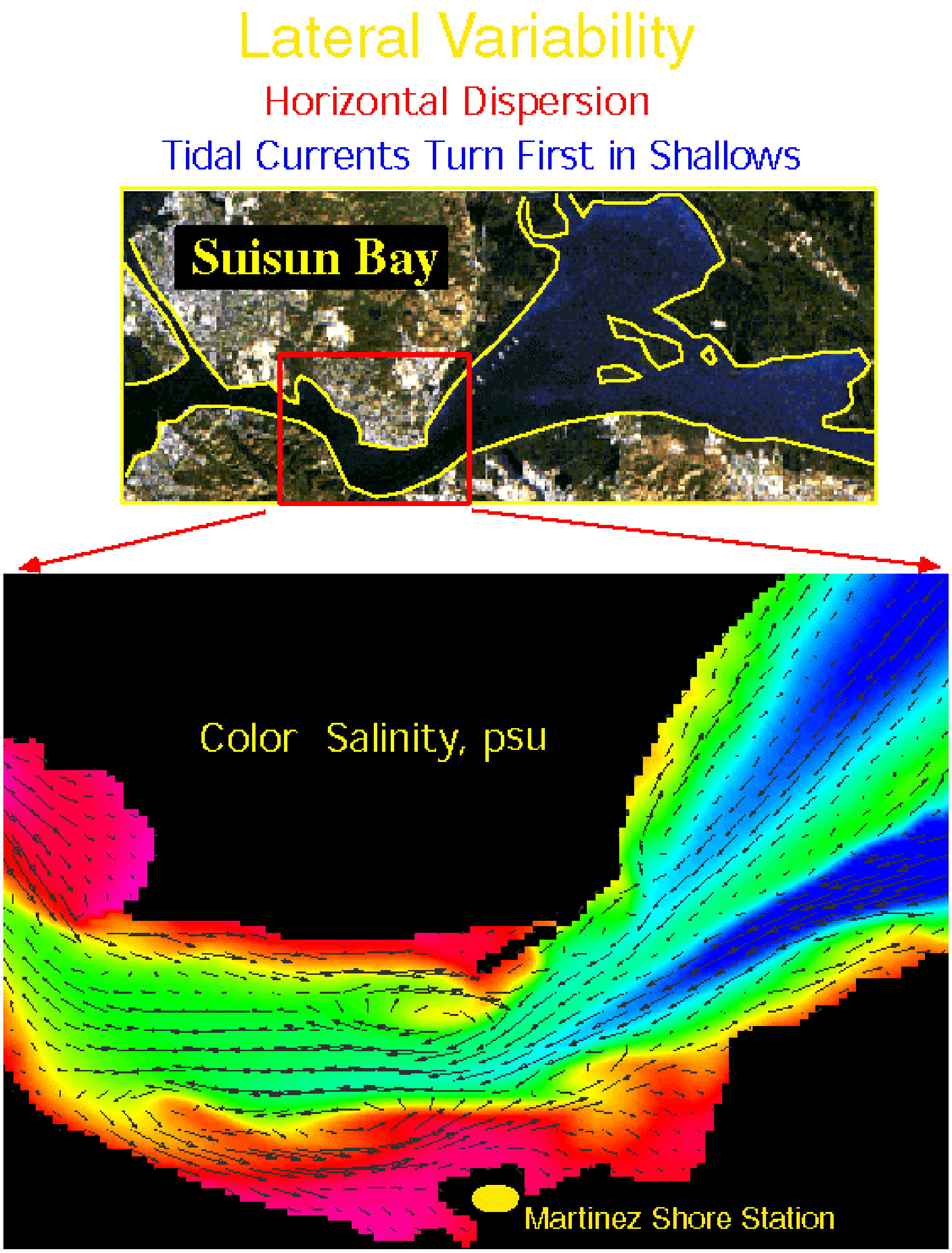


Figure 14. Numerical model results computed using TRIM (Cheng, Casulli and Gartner, 1993) showing the spatial distribution of vertically averaged salinities and velocities in Carquinez Strait near “slack water.” Large lateral gradients in salinity (and, by inference, in other constituents) can occur in “wide” portions of the estuary because the tidal currents “turn” first in the shallows. In this image warmer colors (red) represent high salinity water and the cooler colors (blue) represent relatively fresh water. The arrows depict water motion. The length of the arrow is proportional to the current speed and the arrows orientation denotes the direction or water motion.

1. Lateral Variability

Local bathymetric changes can create lateral velocity shears that can result in significant lateral gradients in the water quality variables measured by the EMP. For example, Figure 14 presents two-dimensional model (Casulli and Cheng, 1992; Cheng, Casulli, and Gartner, 1993) results that show the lateral variability in currents at slack water in Carquinez Strait. The tidal currents are weaker in shallow areas near the channel banks and, because of the reduced momentum there, generally turn before the currents in the center of the channel. This difference in tidal current magnitude, and timing, creates the lateral variability observed in the water quality variables of interest to the EMP.

Recommendation

Sample at center channel. If significant lateral variability exists at a given location, then existing, shore-based continuous monitoring stations should be moved to center channel. Any new continuous monitoring stations should be located in the center of the channel where possible. The extent to which measurements made at the sides of the channel differ from those taken in the center of the channel is often unknown. These differences will be site specific, depending mostly on the local bathymetry. Thus, at existing sampling locations (like the Martinez station), the EMP needs to determine if the differences between sampling at the shore versus sampling in the center of the channel are of practical significance. If a significant difference exists, then a site change, with sufficient overlap to establish a relationship between the historical site and a new site is recommended.

2. Vertical Variability

In the area of the estuary seaward of X2, baroclinic pressure gradients associated with the along-channel salinity gradient provide an additional transport mechanism, known as gravitational circulation, that is absent landward of X2. Unlike the barotropic pressure gradient, the baroclinic pressure gradient varies with depth and thus can vertically stratify the water column, which, in turn, can create vertical variability in many of the water quality variables of interest to the EMP (for example, see Appendix A, pages A1-A2). Stratification reduces vertical mixing and is therefore ecologically important because these physical conditions directly affect the interactions and exchange among suites of biota (Cloern, 1982; Cloern, 1991; Koseff and others, 1993; Monismith and others, 1996). Thus, measurements of stratification are important in understanding hydrodynamic and ecological processes and are important to numerical modelers who require a reasonable estimate of the vertically averaged salinity to drive their models.

Recommendation

Increase the vertical resolution. Enhancing vertical measurement resolution of conductivity and water temperature (CT) is accomplished by increasing the number of sensors in the vertical array. The number of CT sensors should be increased from two (top and bottom) up to six sensors for salinity measurements at locations in the upper estuary with deep channels (> 10m) where baroclinic pressure gradients are significant – essentially in the channels seaward of Mallard Island. The addition of sensors to monitor turbidity, and fluorescence could be considered at select locations once the CT sensors are established and the new monitoring network is stable. Sensors to monitor turbidity and fluorescence require more frequent maintenance, so their addition must also consider increased maintenance efforts.

3. Along-channel Variability

Basic internal hydraulic theory (Armi, 1986) and hydrodynamic measurements associated with recent Entrapment Zone studies (Burau and others, 1998) suggest a conceptual model of residual circulation based on along-channel bathymetric variability (Figure 15). In this conceptual model, a series of gravitational circulation cells are thought to occur between sills, or shallow points in the channels. Sills are known to hydraulically control two-layer exchange (Armi and Farmer, 1986) and as a consequence tend to be areas of increased turbidity (Estuarine Turbidity Maxima). If correct, this conceptual model suggests one can capture the essence of hydrodynamcally induced spatial variability in water quality variables by sampling at relatively few locations: at the sills and in cells (i.e., between sills).

Recommendation

Establish sampling stations at sills and in cells. We recommend the establishment of continuous CT sampling stations at the following sills: Pinole Shoal[1], the Benicia Bridge[1], and Garnett Point[2] . To monitor locations associated with gravitational circulation cells, continuous CT sampling stations should be established at the Richmond Bridge[1], Carquinez Bridge[1], Port Chicago[2], Reserve Fleet[2], and in Suisun Cutoff[2].[6] Establishing all recommended stations would obviate the need for synoptic sampling (at least for CT data collected at these continuous locations) between stations, because each of the stations along the axis of the estuary are within a tidal excursion of each other. Thus, a representative sample of every water parcel in the channel throughout San Pablo and Suisun bays would theoretically be sampled during some phase of the tide with this design. Moreover, EMP water quality and biological sampling would not need to occur concurrently if the biological sampling was conducted adjacent to or near the continuous water quality stations.

[6] Site with a 1=primary locations, sites with a 2=secondary locations.

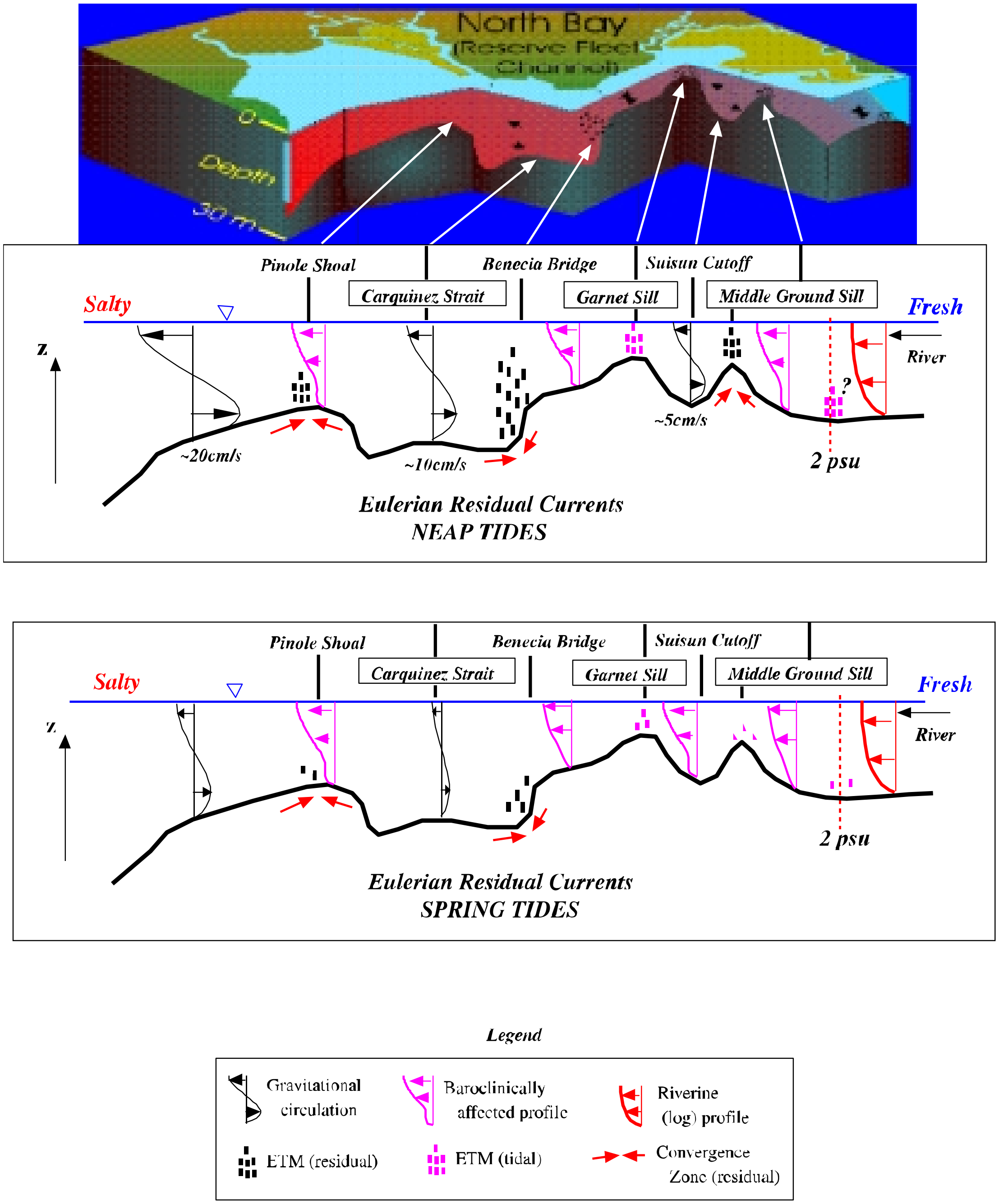


Figure 15. Conceptual model of Eulerian residual circulation for San Pablo and Suisun bays and Carquinez Strait. This model emphasizes the importance of bottom topography (bathymetry) and the difference between conditions that occur during neap and spring tides. For example, sills create tidal (and sometimes residual) time-scale convergence zones that accumulate particulate matter during slack water periods. The density driven residual circulation and the concentrations in the Estuarine Turbidity Maxima (ETM) are greater during neap tides when density driven circulation is greatest.

Finally, any IEP and related biological sampling that is conducted near these hydrodynamically distinct sampling locations, would have important water quality data available for synthesis with the biological data.

4. Shallow-water habitat

A large portion of San Pablo and Suisun bays is shallow water habitat ($\leq$ 2 meters). These shallow water areas are thought to be ecologically important for primary production, spawning and rearing. The restoration of shallow-water habitat is a cornerstone of the CALFED Ecosystem Restoration Plan. Yet, the EMP currently only samples these shallow water areas in San Pablo and Suisun bays once a month.

Recommendation

Monitor shallow-water habitats downstream of X2. Establish continuous CT sampling stations at representative shallow-water habitat sites in San Pablo, Grizzly, and Honker bays.

C. Issues and Recommendations for Water Quality Monitoring Upstream of X2 (Upstream of Chipps Island through the Sacramento-San Joaquin Delta)

Just as for the regions downstream of X2, the EMP needs a monitoring strategy that accounts for the temporal and spatial variability in water quality conditions upstream of X2. In the delta (landward of X2) the flows are driven purely by water surface slopes, or barotropic pressure gradients. Unless the currents are very weak, barotropically driven flows are generally vertically well mixed. Thermal stratification can be locally important in shallow water areas with weak currents during summer; however, thermal stratification is thought to be relatively unimportant in the upper estuary as a whole.

1. Lateral variability

Lateral variability in water quality may also exist at several locations upstream of X2. The delta geometry is complex with numerous channel junctions and localized inputs (e.g., agricultural return water) that can differ substantially in water quality. Such variability could mean that the continuous data collected at shore-based fixed stations is not representative of conditions in the local area.

To investigate the potential for lateral variability upstream of X2 we compared continuous data collected at two shore-based continuous monitoring stations (stations 20 and Station 30, Figure 16) in the delta to monthly discrete data collected from adjacent mid-channel locations. Discrete and continuous measurements of dissolved oxygen, pH, conductivity (specific conductance), and water temperature were all compared. The results uniformly suggest negligible

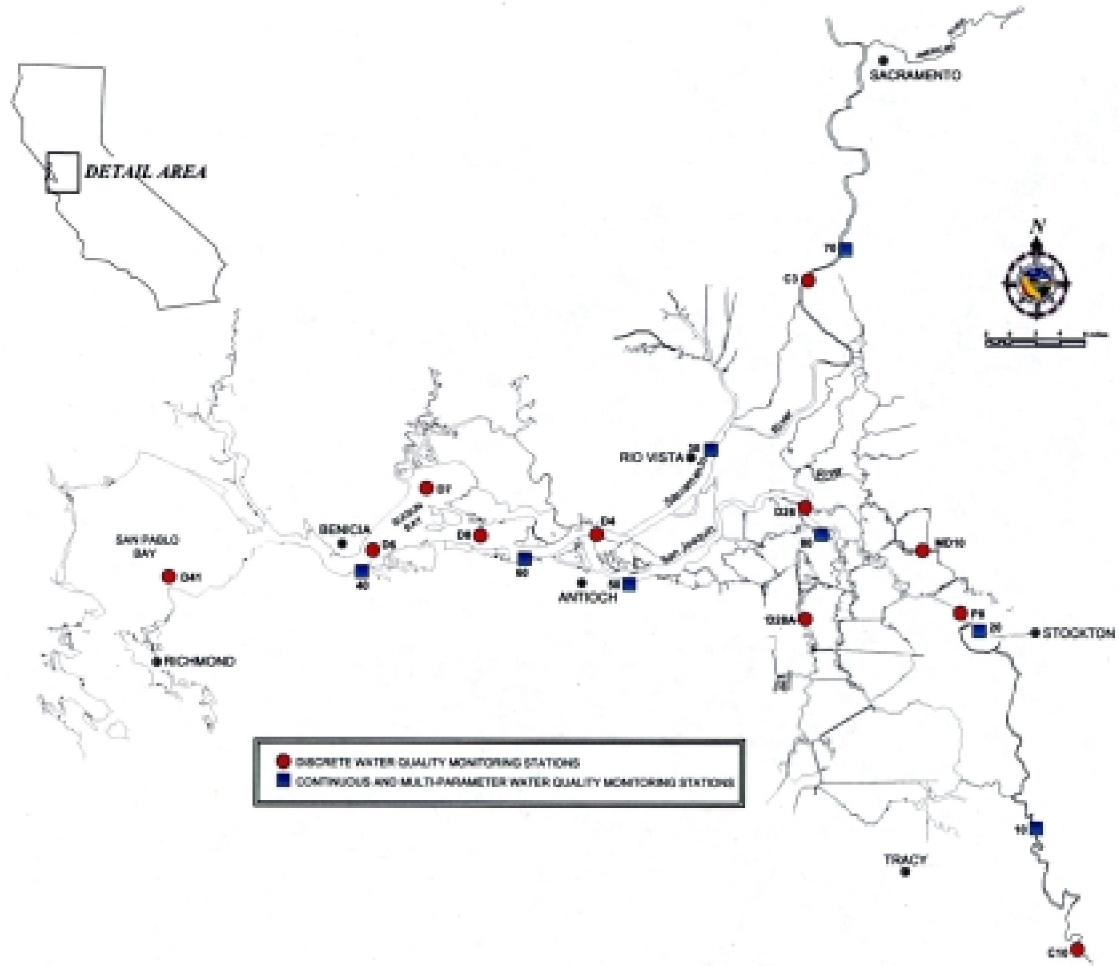


Figure 16. Discrete and continuous EMP monitoring stations as required by Water Right Decision 1641.

lateral variability exists at these locations for the constituents examined (Appendix B, pages B8 – B15). Some variability in the data sets was noted, especially for pH, but the differences are generally small and more likely related to measurement accuracy. Although the results from these sites do not reflect conditions throughout the delta, the results do suggest the data from the fixed, continuous monitoring stations at Rio Vista (Station 30) or Rough and Ready Island (Station 20) are providing a reasonable measure of surface water quality conditions in the local water body.

Recommendation

Retain the shore-based continuous monitoring stations. In general we recommend retaining all of the existing shore-based continuous monitoring stations. Existing monitoring data show measurements from Station 30 (Rio Vista) and Station 20 (Rough and Ready Island) are representative of the local water body, so we recommend no change in the location of these stations (e.g., moving the stations from shore to center channel). However, this sort of analysis is necessary for the other monitoring stations. If these analyses show substantial lateral variability exists at some locations, then options for station relocations should be evaluated. Finally, we recommend completion of an intensive survey to determine if lateral variability is an issue as standard operating procedure in the establishment of new shore-based continuous monitoring stations. In its simplest form, this survey would require numerous, repeated measurements of water quality conditions across the water body for one complete tidal cycle each season. Lateral variability would exist if the variation in measurements across the water body were significantly greater than the seasonal or annual variation typical of the local water body.

Augment continuous monitoring with discrete sampling. To augment the continuous data, we recommend the collection of water samples for laboratory analysis of nutrients, total suspended solids, volatile suspended solids, dissolved solids, and chlorophyll approximately every 35 days (i.e., alternating spring/neap tidal cycles) during routine maintenance visits to the continuous monitoring stations. Secchi disk depth should also be measured each time the continuous stations are visited. Discrete measurements of continuously monitored constituents could also be collected as a form of quality control for the continuous data.

2. Vertical variability

Upstream of X2, vertical variability (or water column stratification) may not exist in many locations. Barotropic forces dominate hydrodynamic processes throughout most of the delta, and intense tide-induced vertical mixing is, in most cases, strong enough to overcome temperature stratification. An exception to this is dissolved oxygen concentrations in the Stockton Ship Channel, where localized biotic and abiotic processes differ with depth, time of year, and location resulting in vertical differences in dissolved oxygen. Another exception may be in some lacustrine habitats within the delta (e.g., Mildred Island) where water residence time is greater and vertical mixing is weak.

The hypothesis that vertical variability may not exist in delta channel habitats was tested using EMP conductivity and water temperature data collected from monthly vertical casts of submersible sensors at three stations (D4, D28A, and P8, see Figure 16 for station locations). Results show vertical variation in conductivity and temperature occurs at all delta stations examined during some months of the year (Appendix A). The presence of water column stratification did not show an obvious seasonal pattern. These data were all collected at or near high slack tide, when stratification can be most evident; thus, the vertical variability noted in these data may not persist throughout the tidal cycle.

<u>Recommendation</u>

Increase vertical resolution. The presence of vertical variability upstream of X2 suggests vertical sensor arrays are needed at some locations to more completely characterize water quality conditions in the Delta. Such vertical arrays should be established at select locations at first to provide more detailed data on the extent and duration of water column stratification. Initially we recommend expanding the vertical array of sensors at Station 20 (Rough and Ready Island) and establishing a vertical array of sensors at Mildred Island (see discussion below under Shallow-water habitat).

3. Shallow-water habitat

Shallow-water habitat is defined here as wetland habitat less than or equal to 2 m in depth. Channelized waterways greater than 2 m deep are by far the most prevalent wetland habitat type in the delta. Some lacusterine and subtidal shoal habitat is also present in the delta. Intertidal mudflat and marsh plains are largely absent, but some remnant patches do exist (Atwater, 1979). Upstream of X2, Shallow-water habitats include some lacusterine and subtidal shoal habitat as well as intertidal mudflat and marsh plan habitats. Shallow-water habitat is not well sampled by the EMP. Current thinking suggests this habitat is vital to a variety of biota, and Calfed’s Ecosystem Restoration Plan identifies the restoration of shallow-water habitat as a high priority for the delta. Monitoring water quality in select shallow-water habitat locations should be a high priority given the potential for substantial increases in shallow-water habitat, its importance to a variety of biota, and its under-representation in the current EMP.

Recommendation

Establish continuous monitoring sites in shallow-water habitat. We recommend establishing continuous monitoring stations in Sherman Lake, Franks Tract, the Yolo Bypass tow drain, and Mildred Island as a means to collect at least conductivity and temperature data. A multiple sensor vertical array should be established at Mildred Island, given its depth and known variability in water quality conditions. Measurements of turbidity (measured as optical backscatter) and fluorescence could be considered for addition at a later time. A special study should be conducted to investigate the feasibility of establishing continuous monitoring stations in some intertidal wetland habitats.

4. Discrete Versus Continuous Station Redundancy

In the existing EMP, samples for water quality analysis are collected monthly (discrete samples) at stations C3, C10 (by van), and Station P8 (by boat). Continuous monitoring stations exist upstream of C3 (Station 70, Sacramento River at Hood), downstream of C10 (Station 10, San Joaquin River at Mossdale), and slightly upstream of P8 (Station 20, Stockton Ship Channel at Rough and Ready Island) (Figure 16). The continuous and discrete data are collected at a depth of 1 m. The discrete data may provide no additional information to that collected at the continuous stations. If this is true then the effort dedicated to the discrete sampling at these stations should be considered for reallocation to other aspects of the EMP.

To investigate the existence of station redundancy we compared continuous data collected at the three shore-based continuous monitoring stations (stations 70, 10, and 20) to monthly discrete data collected from associated discrete monitoring stations (stations C3, C10, and P8, respectively). Constituents compared included, dissolved oxygen, pH, conductivity (EC), and water temperature. The results uniformly suggest the discrete values track changes noted in the continuous sampling record (Appendix B, pages B1 – B11). Some variability in the data sets was noted, especially for pH, but the differences are generally small and most likely related to measurement accuracy.

The results of this analysis show the water quality data (i.e., water temperature, EC, pH, and dissolved oxygen) collected at the three discrete stations (C3, C10, and P8) are duplicative of the data collected at the three continuous monitoring stations (70, 10, and 20 respectively).

Recommendation

Reduce station redundancy. We recommend discontinuing the discrete sampling efforts at stations C3, C10, and P8. To ensure the continuation of the full compliment of discrete data, we recommend the collection of water samples for laboratory analysis of nutrients, total suspended solids, volatile suspended solids, dissolved solids and chlorophyll approximately every 35 days during routine maintenance of the continuous monitoring stations. Secchi disk depth should also be measured each time the continuous stations are visited. Discrete measurements of continuously monitored constituents could also be collected as a form of quality control for the continuous data.

5. Water temperature monitoring

Water temperature is an important water quality constituent that is easily measured on a continuous basis. Although the EMP has collected monthly measurements of water temperature at all discrete sampling sites, continuous time series of water temperature are much more useful to understanding the ecological influence of water temperature. Although surface water temperature is continuously monitored at several locations in the upper estuary (Figure 17), the network of stations is incomplete and the stations may not be situated to maximize our understanding of how water temperatures affects important biotic processes (e.g., the timing and rate of reproduction and growth).

Ambient conditions, water residence time, and the temperature of source waters largely determine water temperature in the upper estuary. A seasonal pattern in surface water temperature is well known for the delta with winter-spring minimums and summer-fall maximums (e.g., Appendix B, page B-7). Water temperature is known to directly affect the timing and location of fish and zooplankton reproduction and growth rates. Monitoring the spatial and temporal changes in water temperature will provide important environmental information useful in: 1) understanding the life history patterns of important species; 2) the development of deterministic models; and, 3) the real-time management of project operations.

Recommendation

Establish a water temperature-monitoring network. A special study is needed to determine an appropriate design for a water temperature-monitoring network. A two-year effort (one year of field data collection and one year of analysis) would be used to develop a recommended monitoring network. The data collection effort would consist of deploying in-situ water temperature loggers at numerous locations throughout the delta from February through October. The data would be analyzed to determine the spatial and temporal variability in water temperature. Tidal filters would be used to determine the spring/neap and seasonal variability. Airborne remote sensing, with a sensor in a thermal IR band, could also be useful. Remote sensing could provide large synoptic coverage for a better understanding of the spatial variability in water temperature. An understanding of the spatial variability in water temperature would be used to develop recommendations for a continuous water temperature-monitoring network.

6. Water clarity

Monitoring water clarity has mainly occurred as monthly measurements of secchi disk depth and turbidity. How primary production is affected by changes in water clarity needs further investigation. Phytoplankton concentrations within the delta have declined since 1975 (Lehman, 2000). Four factors thought to most affect phytoplankton production in the delta are nutrient concentrations, water residence time, grazing rates, and water clarity,. EMP monitoring data show nutrient concentrations are rarely limiting to phytoplankton production in the delta. There is no evidence that water residence time has changed substantially. Grazing pressure downstream of X2 have substantially changed with the establishment of *Potamocorbula amurensis* (Alpine and Cloern, 1992, Hymanson and others, 1994), but the influence of benthic grazing in the delta is unknown. Secchi disk depth data show waters in many parts of the delta have generally increased in clarity over the last 25 years (Figure 18). We do not understand why opposing trends in phytoplankton concentrations and water clarity exist in the delta, although changes in grazing rates –particularly benthic grazing rates—could be important.

<u>Recommendation</u>

Investigate water clarity. A special study is needed to further investigate the changes in water clarity and understand how water clarity in the delta affects phytoplankton production. Such a study would likely require EMP staff working in partnership with a post-graduate researcher. Although existing EMP data would be used, some experiments may also be necessary. Development of a model to describe water clarity/light penetration dynamics and the relationship to phytoplankton production would be a key product of this research; however, this work would also evaluate the existing monitoring strategy and propose changes if needed.

V. Opportunities for Coordination With Other Programs and Addressing Complex Issues

In this section we describe the levels and types of coordination among the EMP and other established monitoring programs in the San Francisco Estuary. In addition, this section considers monitoring needs as they relate to two complex issues, organic carbon and contaminants.

A. Coordination among established water quality monitoring programs

The EMP coordinates with a number of established water quality monitoring programs. The level and type of coordination varies depending on the program and sponsor. This section provides some general information on the water quality monitoring programs the EMP does coordinate with, as well as details on

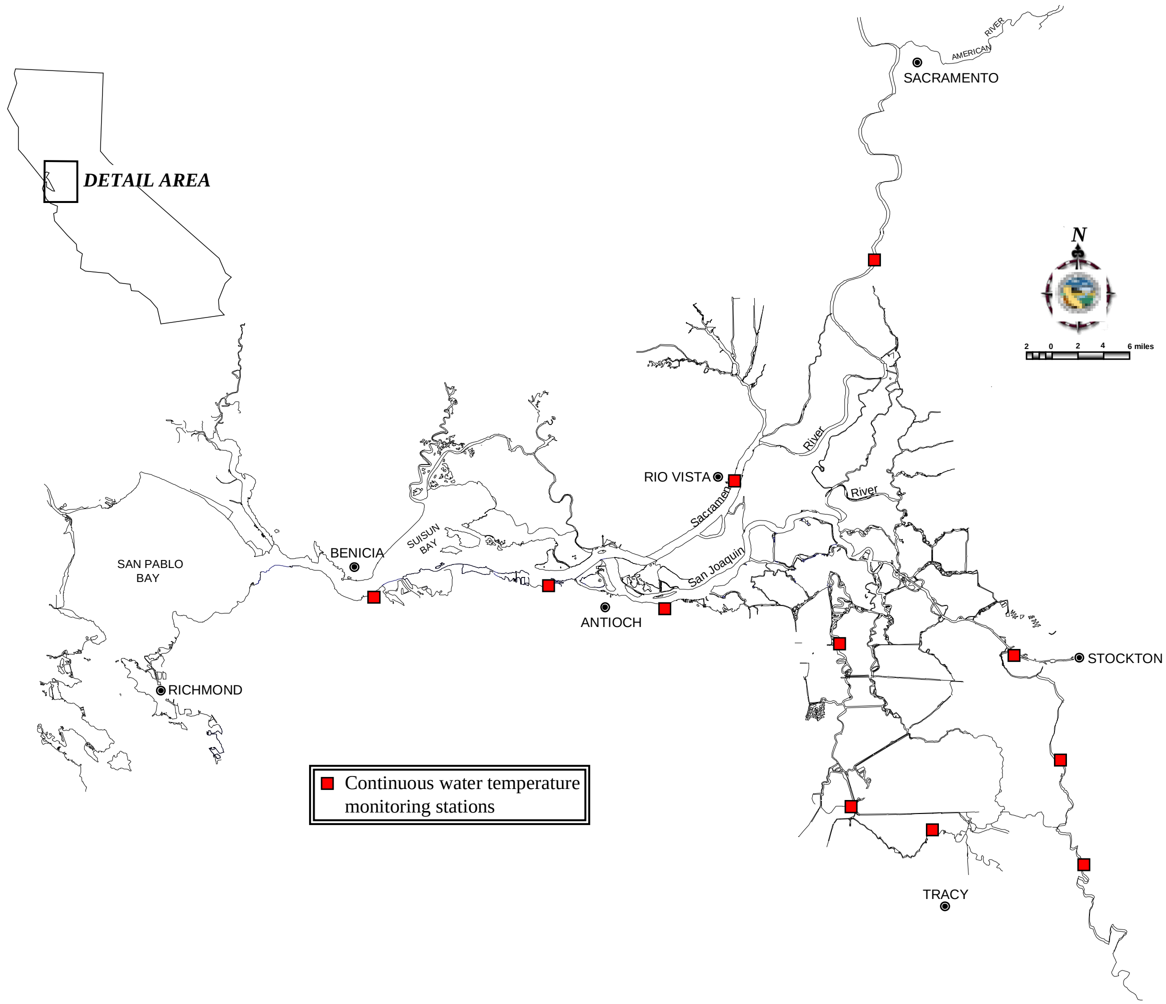


Figure 17. Locations of continuous water temperature-monitoring stations in the upper San Francisco Estuary.

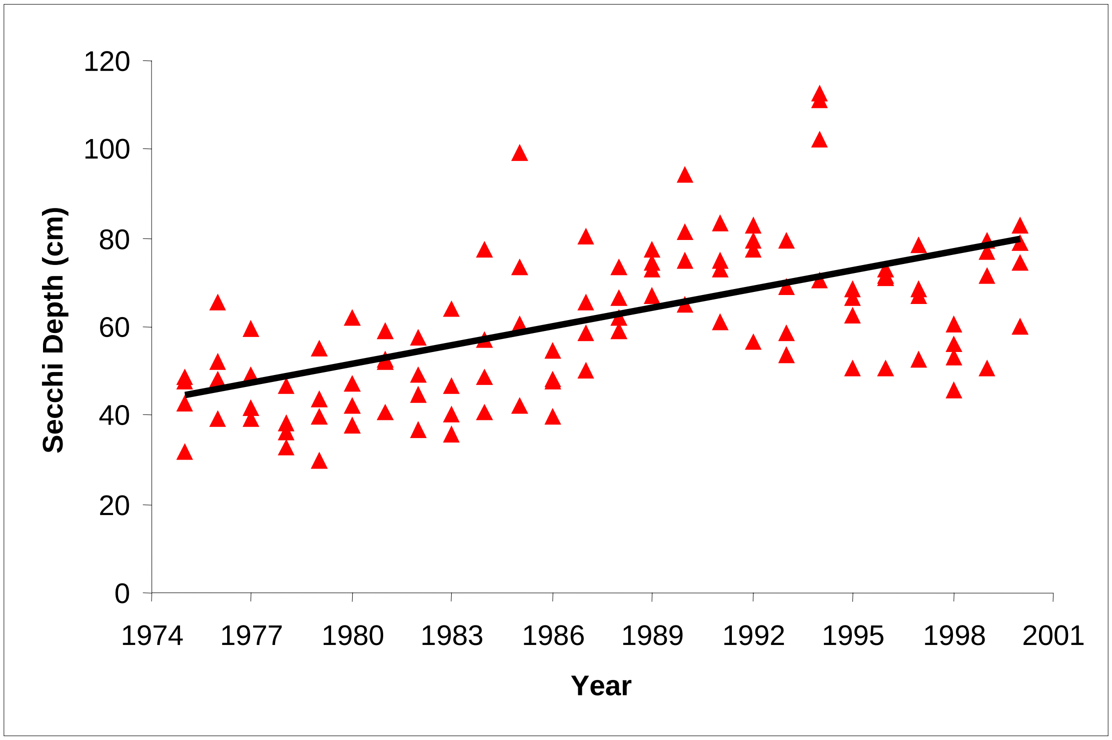


Figure 18. Average annual secchi disk depth in the central delta region, 1975 – 2000.

the level of coordination. Issues related to monitoring organic carbon and contaminants monitoring are also considered and specific recommendations are provided.

The EMP coordinates with other DWR water quality-monitoring programs operating in the upper estuary (Figure 19). Coordination is both active (e.g., direct funding or sharing of staff and resource) and passive (e.g., communications to share information and increasing compatibility in sampling methods and data). The DWR Central District operates a number of continuous monitoring stations in the delta (Figure 20). These stations mainly provide continuous conductivity and tidal stage data from the central and south delta, but water temperature is also monitored at a few locations. The EMP provides funding for the operation and maintenance of some stations. EMP and Central District staff also share information related to instrumentation.

The DWR Division of Operations and Maintenance operates continuous monitoring stations at several water exports sites in the delta (Figure 20). These are multi-parameter stations monitoring conductivity, water temperature, pH, dissolved oxygen, and fluorescence. Coordination with EMP staff generally relates to instrumentation and operating procedures (Figure 19).

The DWR Municipal Water Quality Investigations (MWQI) program monitors delta waters to evaluate drinking water quality (Figure 20). Much of the recent work has focused on total organic carbon (TOC) and trihalomethane formation potential, but program staff also conducts a sanitary survey of State Water Project water supplies. The MWQI program has received CALFED funding to establish continuous monitoring instruments for TOC at three locations in the Delta (i.e., Sacramento River, San Joaquin River, and Clifton Court Forebay). MWQI and EMP staff has worked together to establish continuous monitoring instruments at the EMP continuous monitoring Station 70 (Sacramento River), and MWQI staff has consulted with EMP staff in establishing instruments at the other two locations.

The EMP does not monitor water quality conditions in Suisun Marsh, or Central or South San Francisco bays. The DWR Suisun Marsh program monitors EC and water stage at numerous sites in the Marsh. Coordination with the EMP already exists primarily in the form of staff support for maintenance and operation of the monitoring stations. This relationship has facilitated standardization of monitoring equipment and procedures between the two programs. The recommended special study to develop a network of continuous water temperature monitoring sites presents an opportunity for additional coordination. This special study should consider Suisun Marsh as well as the delta. The establishment of any temperature monitoring devices in the marsh should be integrated with the existing monitoring network to the extent possible.

Monitoring basic water quality conditions in Central and South San Francisco bays is primarily accomplished through two U.S. Geological Survey Programs. The USGS National Research Program (NRP) based in Menlo Park, CA has conducted monthly cruises along the axis of the estuary from lower South Bay to Rio Vista on the Sacramento River since 1969. Set stations are sampled to measure basic descriptors of water quality: EC, water temperature, dissolved oxygen, chlorophyll, turbidity, and suspended solids. Submersible instruments are used to collect these measurements through the water column. The EMP maintains an ongoing relationship with the USGS staff responsible for this monitoring program. Most coordination has focused on the use of comparable sampling methods and instrumentation, to ensure data comparability. For example, the EMP uses the same submersible instrumentation as the USGS. The EMP is funding development of software to post-process the data collected from the submersible instrumentation. This software will be made available to the USGS.

Through the Interagency Ecological Program, DWR funds the USGS district office to maintain and operate a series of continuous monitoring stations at eight locations between Carquinez Bridge in Carquinez Strait, and San Mateo Bridge in South Bay. Water temperature and EC are monitored at all stations and suspended solids are monitored at some locations. Coordination with the EMP is mainly through contract administration and instrumentation issues. This coordination could be improved in terms of increasing the ease of data accessibility (i.e., one-stop shopping for basic water quality data collected throughout the estuary).

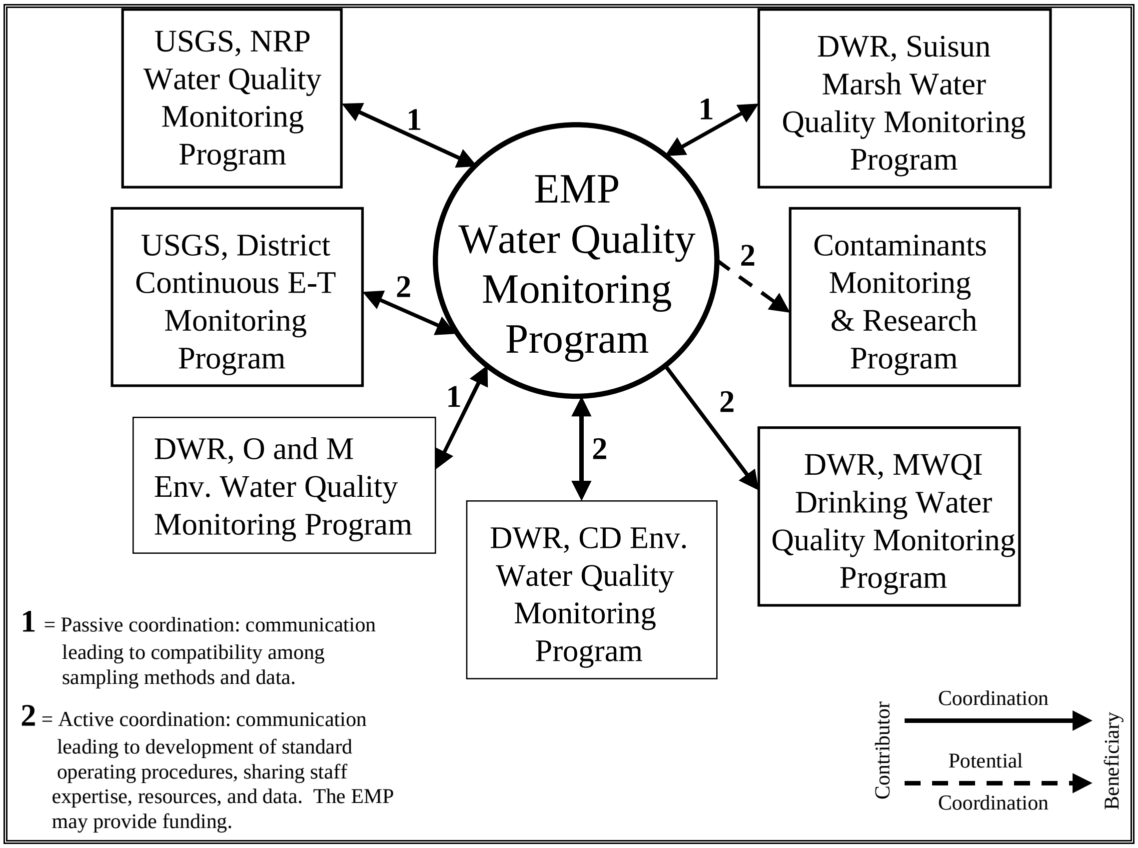


Figure 19. Illustration of the ways the EMP water quality monitoring element coordinates with other existing and potential monitoring programs. See text for details.

These USGS monitoring programs do a good job of collecting the most essential water quality data in the lower estuary. Reasonable coordination between these programs and the EMP does exist. Although more intensive monitoring or monitoring other constituents may be appropriate in Central and South bays, it is probably not cost effective for the EMP to expand into these areas. If more intensive monitoring of water quality conditions in the lower estuary is desired – and we have no indication that it is— it seems most cost effective for the USGS to take on this additional monitoring, assuming funding from other sources is forthcoming.

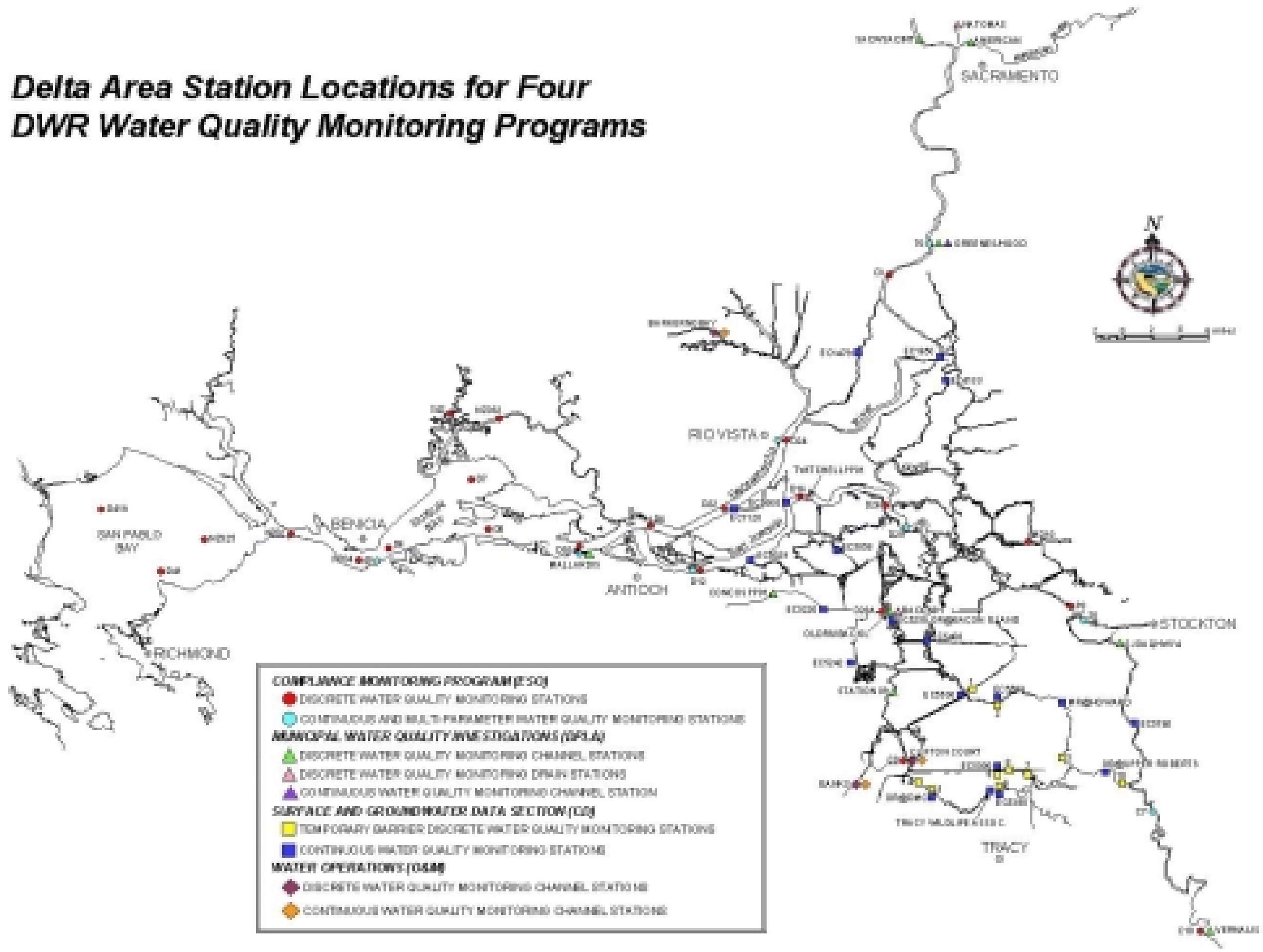


Figure 20. Locations of continuous and discrete monitoring stations sampled by various DWR water quality-monitoring programs in the Sacramento-San Joaquin Delta.

The USBR also operates numerous shore-based continuous monitoring stations in the delta. Conductivity is the only constituent monitored at all of these stations, and many of the stations provide data used in determining compliance with SWRCB salinity standards. There is little coordination between the USBR and DWR continuous monitoring programs. Arthur and other (1996) were tasked with reviewing the existing continuous monitoring programs of the two agencies and developing recommendations on ways to increase coordination and provide more meaningful data. Arthur and others (1996) found the DWR and USBR continuous monitoring programs could be improved by increasing coordination, reducing site duplication, developing of standard operating procedures, and jointly considering the need for new sites. Unfortunately, none of the recommendations from Arthur and others (1996) were implemented.

<u>Recommendation:</u>

Interagency review of the continuous monitoring programs. We recommend interagency review of the work by Arthur and others (1996), with the goal of developing an implementation plan acceptable to the agencies.

B. Organic carbon

Organic carbon is a constituent of interest in both environmental water quality and drinking water quality. Measurement of bioavailable organic carbon can help us to understand food web dynamics. Measurements of total organic carbon can indicate the potential for trihalomethane formation, which is important to water treatment facilities. Thus, monitoring the various forms and concentrations of organic carbon in the upper estuary would benefit from coordination between environmental and drinking water quality monitoring programs.

Total organic carbon (TOC) consists of dissolved organic carbon and particulate organic carbon. Measurements of TOC, however, include both labile (readily available) and refractory carbon, the latter being material that has a long biochemical residence time and probably does not react much within the estuary. Thus, TOC measurements alone do not indicate what is available for consumption by heterotrophic organisms (i.e., bioavailable carbon). Recent work by Sobczak and others (in prep.) found the two most important sources of bioavailable carbon for the delta were dissolved organic carbon from external riverine sources and particulate organic carbon derived from internal phytoplankton production. Further, Mueller-Solger and others (in prep.) found chlorophyll a concentrations in delta waters were highly predicative of *Daphnia magna* growth rates.

Measurements of biochemical oxygen demand (BOD) can provide data that should inform us about the amount of total labile carbon. BOD measurements to estimate labile carbon are especially useful if chlorophyll a is also measured. Continuous and discrete measurements of chlorophyll a should provide data needed to determine phytoplankton biomass and production within the delta. It is also possible to compare BOD and chlorophyll a measurements among data sets within the San Francisco Estuary and other locations, permitting a much broader understanding of lower trophic dynamics.

Recommendation:

Monitor Biochemical oxygen demand, chlorophyll a, and flow. We recommend the EMP undertake a pilot study to investigate the feasibility of conducting 5-day BOD at 20 °C on a routine basis. Sampling should initially occur at continuous monitoring Stations 70 and 10 (Figure 16). These stations collect data, including continuous measures of chlorophyll a fluorescence, from major inflows to the delta. Discrete samples for size-fractionated chlorophyll a concentrations should also be collected with the BOD samples. Continuous monitoring of water flow should also occur at these stations to allow calculations of fluxes in chlorophyll a. The frequency at which BOD tests should be conducted is unknown. Discussions with USGS NRP staff who recently completed numerous BOD tests over an 18-month period, should help to define the sampling frequency. This pilot study should continue for two years, concluding in a written evaluation with recommendations for future monitoring.

C. Contaminants monitoring

Monitoring the occurrence and concentrations of contaminants in the upper estuary is not something the ERP is prepared to take on. Although the program has historically collected samples for pesticide and heavy metal concentrations, this sampling effort was discontinued in 1995 because it was not producing meaningful results. The collection of high quality data on the distribution and concentration of contaminants is not a trivial matter. The regular sampling strategy employed by the EMP is not conducive to contaminants monitoring which should probably vary in intensity and location throughout the year, based on events related to land use and runoff patterns. Additionally, DWR and USBR –the agencies responsible for the funding and implementation of the EMP– do not directly contribute contaminants to the system, so these agencies cannot justify the high cost associated with implementation of an appropriate contaminants monitoring program.

Contaminants monitoring in the estuary was an issued addressed in the CALFED sponsored Comprehensive Monitoring Assessment and Research Program (CMARP). A technical appendix to a CMARP final report (Thompson and others 1998) provided the following information related to contaminants monitoring in the estuary:

> There are currently several major contaminant monitoring programs in the Bay-Delta (Table 2). However, only a few are ongoing programs. The San Francisco Estuary Regional Monitoring Program (RMP) is the

largest and most comprehensive program. The RMP monitors water, sediment, animal tissue, and contaminant effects, and conducts a series of pilot and special studies to support the monitoring. The RMP only monitors in San Francisco Bay up to the confluence of the main Rivers. The Sacramento River Watershed Program (SRWP) and Sacramento Coordinated Monitoring Program (SAC CMP) are both conducted primarily in the Sacramento River, but several sites are sampled in the Delta, downstream to Ryer's Island. Two Category III pilot projects, one on aquatic toxicity and the other on fish tissue contamination, are of short duration, but the information they generate could be incorporated into CMARP. CISnet is an EPA and NOAA sponsored program to develop long-term monitoring in San Pablo Bay, scheduled to begin in 1999, which will be conducted by UC Davis, SFEI, USGS, and PRBO. Local Effects Monitoring (LEM) studies in the Bay are conducted by permitted dischargers to assess effects of their discharges. The USGS SF Bay Program conducts studies on important contaminant issues in the Bay.

All of those programs sample a different set of variables at different space and time scales. There has been little coordination or intercalibration among them, except for fish tissue and benthos sampling.

Table 2. Listing of current water quality monitoring programs in the San Francisco Bay and Delta. D=dissolved concentrations; T=total concentrations. See text for abbreviations. Taken from Thompson and others (1998).

	WATER			SEDIMENT			TISSUE		EFFECTS
	Metals	Organics	Toxicity	Metals	Organics	Toxicity	Fish	Bivalve	Benthos
DELTA									
SAC CMP	D, T	D*	X						
SRWP	D, T		X			X	X		X
CAT III			X				X		
BAY									
RMP	D, T	D, T	X	X	X	X	X	X	X
CISnet				X		X	X	X	X
LEMPs				X	X				X
USGS SF Bay		D*		X				X	X

* selected pesticides only

Thompson and others (1998) offered the following recommended approach for contaminants monitoring program.

Three related components of a comprehensive Bay-Delta monitoring program are recommended: Status and Trends Monitoring, Focused Monitoring of recognized problems, and Research that will help interpret monitoring information better, or to make better monitoring measurements. Together information from those monitoring efforts will contribute to an overall understanding of sources and loadings, fate and transport, and biological effects of contaminants.

As indicated by Thompson and others (1998), a dedicated program involving both monitoring and research is required to properly document the concentration, fate and transport of contaminants in the upper estuary. Although the EMP can play a role in a coordinated contaminants monitoring program, it is not in a position to develop or lead such a program. Development and implementation of a contaminants monitoring program is most appropriately addressed through the CALFED water quality program.

VI. Proposed Water Quality Monitoring Plan

In this section, the information presented above is used to describe a sampling design for monitoring water quality in the upper estuary. Recommendations for sampling stations and special studies presented in Section IV are briefly presented as a summary of earlier recommendations. Station locations for the recommended water quality-monitoring program in the upper estuary are shown in Figure 21. Table 3 provides information on station descriptions, type of instrumentation, and constituents monitored.

A. Recommendations for water quality monitoring and special studies:

1. General considerations

There are several general considerations that apply to the EMP water quality-monitoring element. These issues are listed in order of priority in terms of their consideration in developing recommendations for program changes.

- Representativeness[7]
- Continuity
- Data management
- Continuous and discrete sampling
- Discrete sampling periods
- Estimate fluxes
- Tidal cycle aliasing
- Characterize water column structure
- Incorporate new techniques
- Expand analysis and information

[7] In addition to its general consideration, a specific recommendation is made to discontinue boat-based discrete vertical profiles but retain boat-based continuous horizontal profiles.

2. Downstream of X2

Several recommendations are presented which affect the location and intensity of water quality sampling downstream of X2.

- Sample at center channel
- Increase vertical resolution
- Establish sampling stations at sills and in cells
- Sample shallow-water habitats

3. Upstream of X2

Several recommendations are presented which affect the location and intensity of water quality sampling downstream of X2.

- Retain the existing shore-based continuous monitoring stations
- Augment continuous monitoring
- Increase vertical resolution at select locations
- Establish continuous monitoring sites in shallow-water habitat
- Reduce station redundancy

4. Recommendations for special studies:

Numerous special studies are recommended to verify the appropriateness of the recommended water quality-monitoring program or to augment the capabilities of the program. Specifically, special studies are recommended to investigate:

- Tidal cycle aliasing
- Development of a water temperature monitoring network
- The importance of water clarity in primary production
- The ability and utility of monitoring BOD and size fractionated chlorophyll a
- Coordination and streamlining of the continuous monitoring network maintained in the estuary by DWR, USBR, and USGS
- Expand data analysis/interpretation methods

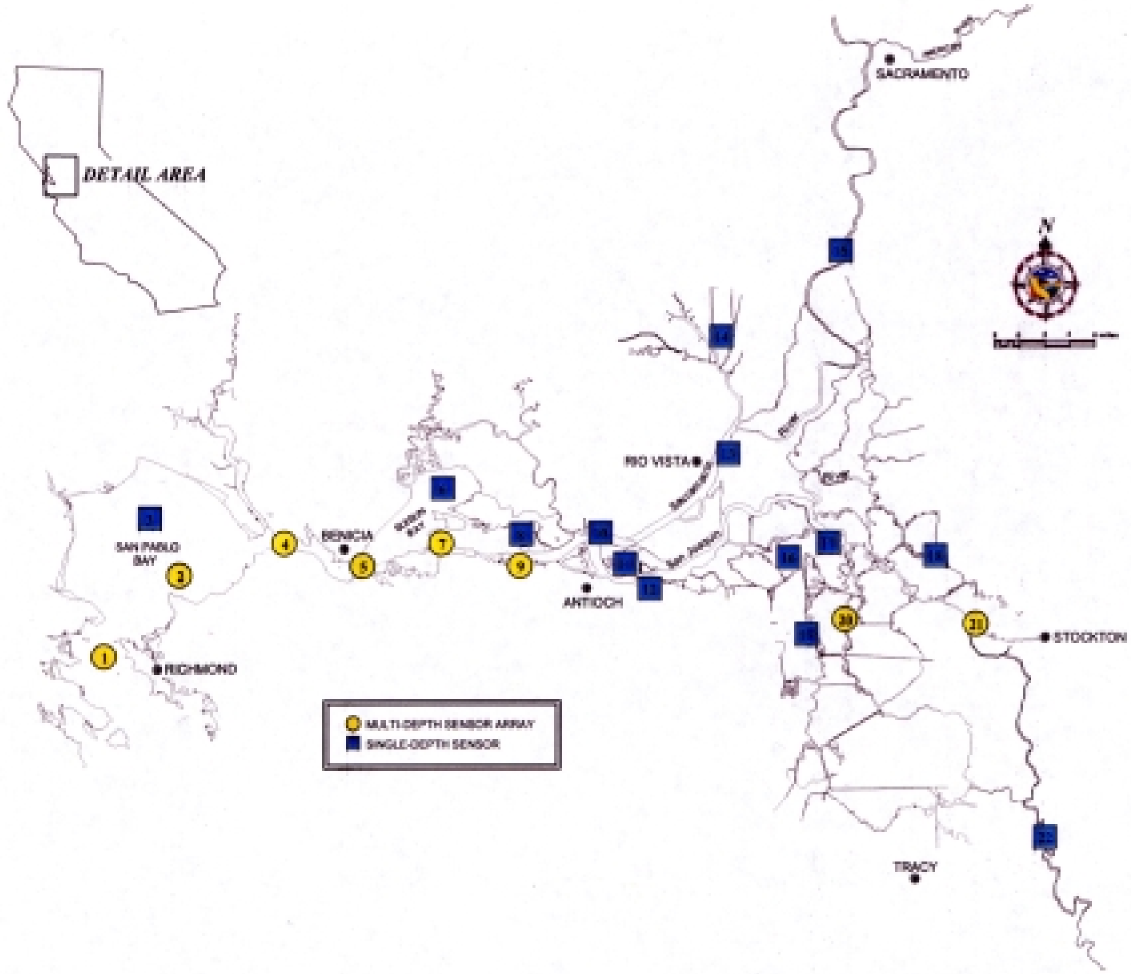


Figure 21. Proposed water quality monitoring sites for the EMP.

Table 3. Summary information on stations, instrumentation, and constituents monitored as part of the recommended EMP water quality-monitoring element.

Station Number[1]	Station Description	Discrete[2]	Twin Sensor[3]	Multi-parameter[4]	Need[5]	Comments[6]
1	Richmond Bridge, center Channel		X		3,4	New station. Multi-depth sensor array.
2	San Pablo Bay near Pinole point	X	X		3,4	This station replaces discrete station D41. Multi-depth sensory array.
3	San Pablo near the Mouth of the Petaluma River		X		3	New station for water quality, although this would provide continuous data in an area of discrete horizontal monitoring. Single depth sensor.
4	Carquinez Bridge, center channel		X		3,4	New station. Multi-depth sensor array.
5	Benica Bridge, center channel	X	X		1,3,4	This station could ultimately replace the shore-based Martinez multi-parameter station 40, and would replace discrete station D6. Multi-depth sensor array.
6	Grizzly Bay at Dolphin near Suisun Slough	X	X		3,4	This is discrete station D7. Single depth sensor.
7	Suisun Bay at Port Chicago	X	X		1,3,4	This station could be an augmentation to the USBR Port Chicago continuous monitoring station. This station would replace discrete station D8. Multi-depth sensor array.
8	Honker Bay shallows		X		3	New station, single depth sensor
9	Sacramento River at Mallard Island	X		X	1,3,4	This is the Mallard Island multi-parameter monitoring station 60. This station would replace discrete station D10. Multi-depth sensor array.

Table 3 continued. Summary information on stations, instrumentation, and constituents monitored at part of the recommended EMP water quality-monitoring element.

Station Number[1]	Station Description	Discrete[2]	Twin Sensor[3]	Multi-parameter[4]	Need[5]	Comments[6]
10	Sacramento River at Collinsville	X	X		1,3,4	This is the USBR continuous monitoring station at Collinsville. This would replace discrete station D4
11	Sherman Lake	X	X		3,4	Discrete sampling would be re-established at this station (D-1485 Station D11). Single depth sensor .
12	San Joaquin River at the Antioch Ship Channel	X		X	1,4	This is the existing Antioch multi-parameter station 50. Discrete sampling would be re-established at this station. Single depth sensor array.
13	Sacramento River below Rio Vista Bridge	X		X	1,3	This is the Rio Vista multi-parameter station 30. Discrete sampling would be re-established at this station. Singl. depth sensor
14	Yolo Bypass tow drain	X	X		3	New Station. Single depth sensor.
15	Sacramento River at Hood	X		X	1,3	This is multi-parameter station 70. Discrete sampling would replace discrete station C3. Single depth sensor. Flow, Chl a, and BOD also monitored at this station.
16	False River at Franks Tract	X	X		3,4	This would re-establish water quality monitoring at D-1485 Station D19. Single depth sensor.
17	San Joaquin River at Prisoner's Point	X	X		1,2,3	This is continuous monitoring station 80. Expand to year-around operation. Discrete sampling here would replace station D26, if data analysis shows overlap in measured values. Single depth sensor.

Table 3 continued. Summary information on stations, instrumentation, and constituents monitored at part of the recommended EMP water quality-monitoring element

Station Number[1]	Station Description	Discrete[2]	Twin Sensor[3]	Multi-parameter[4]	Need[5]	Comments[6]
18	Dissapointment slough near Bishop Cut	X	X		1,3	This is discrete station MD10. A continuous monitoring station would be established here. Single depth sensor.
19	Old River opposite Rancho Del Rio	X		X	1,3,4	This is discrete station D28A. The continuous monitoring station EC5250 operated by DWR Central District would be expanded to a multi-parameter station. Single depth sensor.
20	Middle River at Mildred Island	X	X		3	This is a new station. Multi-depth sensor array.
21	San Joaquin River at Rough and Ready Island	X		X	2,3,4	This is multi-parameter station 20. Discrete sampling would replace discrete station P8. Multi-depth sensor.
22	San Joaquin River at Mossdale Bridge	X		X	2,3,4	This is multi-parameter station 10. Discrete sampling here would replace Station C10. Single depth sensor. Flow, chl a, and BOD also monitored at this station.

1. See Figure 21 for approximate location of all stations
2. Discrete samples for macronutrients (organic and inorganic nitrogen and phosphorus, and silicate), total suspended solids, volatile suspended solids, dissolved solids, and chlorophyll a, pH, turbidity, dissolved oxygen (DO), conductivity (EC), and water temperature would be collected about every 35 days during normal service visits to continuous monitoring sites. Secchi disk depth would be measured every time the station is visited. pH, DO, EC, and water temperature data would also be used as quality control information for continuous data.
3. Includes continuous monitoring (recording every 15 minutes) of water temperature and EC.
4. Includes continuous monitoring (recording every 15 minutes or every hour) of water temperature, EC, turbidity (optical backscatter), fluorescence, tidal elevation, and meteorological data (air temperature, wind speed and direction, and solar radiation). Fluorescence and turbidity is only monitored 1-m below the water surface. Continuous meteorological data are collected only at stations 5, 12, 13, and 21. Dissolved oxygen is measured continuously only at Stations 20, 24, and 25. Data are telemetered only from stations 5, 9, 13, 15, 18, 20, and 21. Stations 1, 4, 10, 12, and 22 are set-up for modem access.
5. Needs as listed in Table 1.
6. The number of multi-depth sensors in the vertical array varies with station depth. Top sensor in array is at 1-m below the water surface. Single depth sensor located at 1-m below the water surface.

B. Sampling details

The majority of the water quality data obtained from this recommended program are generated by continuous monitoring stations. Two kinds of continuous monitoring stations are proposed: 1) multi-parameter continuous monitoring stations; and 2) twin sensor continuous monitoring stations collecting EC and water temperature data. Multi-depth sensor arrays are recommended at various locations downstream of X2 and at two locations upstream of X2, depending on site-specific considerations (Figure 21). Single depth sensors located at 1-m below the water surface are recommended at all other locations. Discrete samples for chlorophyll a, macronutrients, total suspended solids, volatile suspended solids, dissolved solids, pH, dissolved oxygen, conductivity, water temperature and secchi disk depth would be collected at select stations during service visits to continuous stations, or during cruises to collect benthos and zooplankton samples. Continuous, boat-based horizontal profiles would be conducted during runs to collect zooplankton samples, since these runs will continue to occur at a specific tidal phase (i.e., high slack tide).

1. Multi-parameter continuous monitoring instrumentation

The proposed water quality monitoring program would include several shore-based multi-parameter continuous monitoring stations. Most of the recommended stations are already established. These Multi-parameter stations are equipped with a Schneider Instruments continuous water quality monitor system. This instrument is used to monitor water temperature, pH, dissolved oxygen, conductivity, air temperature, wind direction, wind speed and solar radiation intensity (Table 4).

At the shore-based stations, sample water is continuously collected from a floating pump at a depth of one meter below the water surface. The sample water is pumped to a manifold of water quality sensors inside the Schneider unit. The data generated by the Schneider sensors is scanned about once each second by an Ocean Data Equipment model DACTS-80-26 Data Acquisition, Control and Telemetry System. Data are averaged over each hour (~ 3600 observations per hour) and then stored on a PC SRAM card with a HP1000CX palm-top computer. Data for select constituents is telemetered on the hour.

At select stations, bottom conductivity is measured using a Foxboro model 872 Electrochemical Monitor with an electrodeless probe suspended 1.5 m above the channel bottom. The information from the Foxboro model 872 is recorded on an ORS Environmental DataLogger model DL-150. The DL-150 scans the Foxboro every quarter hour and stores the information.

The DL-150 also scans and stores water stage information that is generated from a JGS model SE-104 incremental encoder with a float and tape. The encoder is set for 100 counts per revolution. As the float rises or falls the DL-150 then adds or subtracts the equivalent of 1/100 of a foot elevation per count of the encoder to a counter, which is set to Mean Sea Level +10ft.

Table 4. Constituents monitored at shore-based continuous multi-parameter stations

Variable	Continuous Measurements[1]	Units
Chemical	Dissolved Oxygen	mg/L
Chemical	Conductivity	µS/cm
Chemical	pH	unit pH
Physical	Water Temperature	°C
Physical	Air Temperature	°C
Physical	Wind Speed	KPH
Physical	Wind Direction	°
Physical	Solar radiation	cal/cm2/min
Physical	Water stage elevation	MSL
Biological	Chlorophyll a (Fluorometric)	Fluo. Units

2. Twin sensor continuous monitoring instrumentation

Twin sensors for conductivity and water temperature (CT sensors) could be deployed in vertical arrays (multi-depth) at bridge piers and off pilings or at single depth in shallow-water areas. Generally, the CT sensors (Figure 22) are attached to an inductive cable kept taught by an anchor weight (Figure 23). For example, Seabird electronics manufactures CT sensors that communicate with a surface-mounted inductive modem. The modem can accommodate up to 100 CT sensors on a single inductive cable. These data would be logged to instruments at the surface and could be telemetered in real-time or accessed via modem.

Figure 22. Seabird in-situ conductivity and water temperature sensor (model SBE37-IM). Photo courtesy of Seabird Electronics.

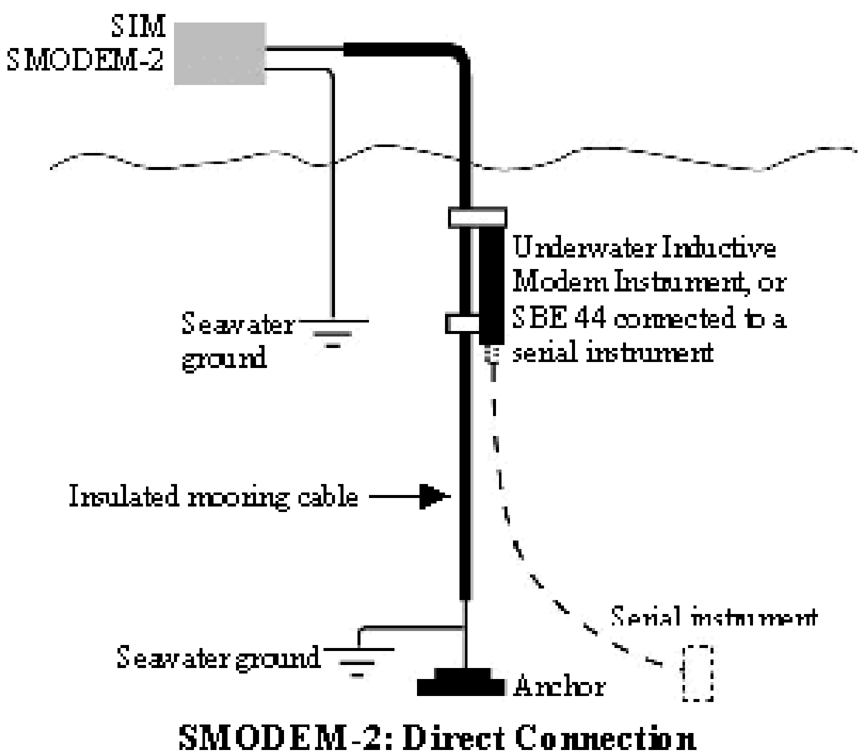


Figure 23. Conductivity-Temperature (CT) sensors suspended using an inductive cable and modem (Courtesy of Seabird Electronics).

3. Discrete sample analytical methods

Discrete water samples are collected on site by pump or Van Doren. Water samples are placed in plastic containers and stored in a refrigerator or freezer away from light. Appendix C provides more details on the constituents recommended for monitoring. Analytical methods for the various constituents are listed in Table 5.

Table 5. Discrete sampling constituents and analytical methods.

Variable	Field and Lab Analysis	Units	Analysis by[1]	Method[2]
Chemical	Total Suspended Solids (TSS)	mg/L	Bryte Lab	EPA 160.2
Chemical	Volatile Suspended Solids (VSS)	mg/L	Bryte Lab	EPA 160.4
Chemical	Todal Dissolved Solids (TDS)	mg/L	Bryte Lab	SM 2540-C
Chemical	Total Organic Nitrogen	mg/L	Bryte Lab	EPA 351.2
Chemical	Dissolved Organic Nitrogen	mg/L	Bryte Lab	EPA 351.2
Chemical	Dissolved Ammonia	mg/L as N	Bryte Lab	EPA 350.1
Chemical	Dissolved Nitrite + Nitrate	mg/L as N	Bryte Lab	Mod. SM 4500-NO3-F
Chemical	Total Kjeldahl Nitrogen	mg/L as N	Bryte Lab	EPA 351.2
Chemical	Total Phosphorus	mg/L	Bryte Lab	EPA 365.4
Chemical	Dissolved Ortho-Phosphate	mg/L as P	Bryte Lab	Mod. EPA 365.1
Chemical	Dissolved Chloride	mg/L	Bryte Lab	EPA 325.2
Chemical	Dissolved Silica (SiO2)	mg/L	Bryte Lab	SM 4500-Si-D
Biological	Chlorophyll a, discrete (spectrophotometric)	µg/L	Bryte Lab	SM 10200H
Biological	Pheophytin a, discrete (spectrophotometric)	µg/L	Bryte Lab	SM 10200H
Chemical	Dissolved Oxygen, Winkler	mg/L	RV Crew	
Physical	Secchi Disk Depth	cm	RV Crew	
Physical	Time	PST	RV Crew	

1. Bryte Lab: DWR Bryte Chemical Laboratory, Bill Nickels, Director.
2. EPA, APHA Standard Methods (SM), and American Society for Testing and Materials (ASTM), some with DWR-Bryte Lab modifications (Mod.)

C. Comparison between existing and recommended program

The recommended water quality-monitoring program would result in a substantial increase in the number of continuous and discrete monitoring stations compared to the existing program. Specifically, the number of continuous monitoring stations would increase from 8 to 22, while the number of discrete monitoring stations would increase from 11 to 18. Much of the increase in the number of continuous monitoring stations is due to increasing the number of shallow-water sampling stations throughout the upper estuary (7 stations total). The addition of continuous stations downstream of X2 and in the western and central delta adds a total of 7 stations. The recommended program directly links discrete and continuous monitoring stations. Thus, although the recommended number of discrete stations is nearly double the existing number of stations, no unique effort is required to collect the discrete samples. Overall, the EMP water quality-sampling network would change from 19 stations to 22 stations if the recommended program were adopted. Table 6 provides a side-by-side comparison of the changes in water quality sampling stations between the existing and recommended program.

Table 6. Side-by-side comparison of water quality sampling stations in the recommended and existing EMP water quality-monitoring element. See Figures 16 and 21 for existing and recommended station locations, respectively.

Recommended Station Number	Recommended Sampling[1]	Existing Station Number	Existing Sampling[1]	Comments
1	C	None	None	Recommended station is a new station for the EMP
2	B	None	None	Recommended station is a new station for the EMP
3	C	D41	D	
4	C	None	None	Recommended station is a new station for the EMP
5	B	40 and D6	B	
6	B	D7	D	
7	B	D8	D	
8	C	None	None	Re-establishes discrete Station D?? sampled under D-1485
9	B	60	C	
10	B	D4	D	The recommended station would utilize the USBR monitoring station at Collinsville
11	B	None	None	Re-establishes discrete Station D11 sampled under D-1485
12	B	50	C	
13	B	30	C	
14	B	None	None	Recommended station is a new station for the EMP
15	B	70 and C3	B	Discrete sampling at Station C3 would be discontinued. Station 70 is the recommended continuous and discrete monitoring station

Table 6, continued. Side-by-side comparison of water quality sampling stations in recommended and existing EMP water quality monitoring element. See Figures 16 and 21 for existing and recommended station locations, respectively.

Recommended Station Number	Recommended Sampling[1]	Existing Station Number	Existing Sampling[1]	Comments
16	B	None	None	Re-establishes discrete Station D19 sampled under D-1485
17	B	80	C	Station 80 is seasonally operated and is recommended for year-around operation
18	B	MD10	D	The recommendation is to establish a continuous monitoring station at MD10 and continue discrete sampling
19	B	D28A	D	The recommended continuous monitoring station would utilize the existing DWR, Central District station
20	B	None	None	Recommended station is a new station for the EMP
21	B	20 and P8	B	Discrete sampling at Station P8 would be discontinued. Station 20 is the recommended continuous and discrete monitoring station
22	B	10 and C10	B	Discrete sampling at Station C10 would be discontinued. Station 10 is the recommended continuous and discrete monitoring station

[1]Sampling can be discrete (D), continuous (C), or both (B).

VII. Plan for converting data into useful information

The timely and thoughtful conversion of data into information is a major issue for any monitoring program. It is not unusual for monitoring programs to devote a majority of the staff time to data collection, severely impeding data management, analysis, and reporting functions. The EMP is no exception. Yet many new tools exist to support data management processes and enhance the informative value of basic monitoring data. These tools combined with existing and expected resources place the EMP in a good position to make substantial improvements in its data management, analysis, and reporting functions. We recommend the following specific steps to address the overall needs for the timely conversion of data to information.

- Hire a person that will develop and oversee all EMP data management and routine reporting processes for the monitoring data.

- Develop and implement routine data management processes. This work would rely heavily on MS Access for data base management. Data would be shared with the public through the Bay-delta Tributaries Data Base. Time series data could be efficiently checked and edited using an IEP funded, USGS developed, computer program known as “Gr.” For more information on this publicly available program see: http://wwwdcascr.wr.usgs.gov/projects.

- Using GIS and other graphical representations, develop reporting tools that would provide basic information on water quality concentrations and distributions over time (e.g., X2 over time, seasonal chlorophyll concentrations in the Delta, water temperature gradients from spring to summer, or delta water clarity over time). Display of basic results would rely on basic graphical representations, GIS, and web-based reporting tools. The web-based reporting tools should be open in architecture to allow the user to choose the period and area of interest.

- Annually prepare a brief “status and trends” report. This report would describe remarkable events occurring each year, update long-term trends in water quality conditions, and relate water quality information to other biological monitoring data. This report could go in the IEP Newsletter or be a stand-alone publication like “The Pulse.”

VIII. Implementation plan:

We recommend the following schedule for implementing changes to the EMP water quality-monitoring element over the next four years.

A. Year One:

- Fill data management/data-to-information position. First priority is to improve/complete EMP data management processes.
- Establish CT sensors at new stations 1-8. Continue duel operation of sensors at Station 5 to test for lateral variability.

- Modify continuous monitoring station 17 from seasonal to year-around operation.
- Begin discrete sampling on alternating spring/neap tides.
- Begin special study to determine continuous monitoring network for water temperature.
- Discontinue discrete monitoring at (van-run) stations C3 and C10 and at (boat-run) station P8. Initiate collection of discrete samples at stations 15, 22, and 21 respectively during routine maintenance visits. Add near-bottom dissolved oxygen and temperature sensors at station P8.

B. Year Two:

- Replace annual report with web-based reporting tools and "status and trends report."
- Initiate interagency (DWR, USBR, and USGS) review of upper estuary continuous monitoring network.
- Initiate a two-year pilot study for BOD, size-fractionated chlorophyll a, and continuous flow monitoring at stations 9 and 22.
- Increase number of discrete sampling stations from 11 to 18. Sample stations 2, 3, 5, 6, and 10-22. Collect discrete samples during continuous station maintenance or as part of the zooplankton or benthos sampling. Constituents sampled would depend on continuous instrumentation.
- Analyze data collected from the special study to determine the continuous monitoring network for water temperature.

C. Year Three:

- Evaluate results and recommendations from the special study to determine a water temperature-monitoring network. Develop an implementation plan and funding proposal.
- Evaluate results and recommendations from station 5 lateral variability study. Decide on final location of monitoring instruments (shore or bridge based).
- Initiate the special study to evaluate sampling bias associated with tidal phase and the "slow boat."
- Evaluate results from interagency review of continuous monitoring network. Depending on results of review, consider establishment of CT sensors at stations 11, 14, 16, 18, and 20.

D. Year Four:

- Begin implementation of water temperature continuous monitoring network.
- Begin evaluation of methods of monitoring water clarity and light transmittance. The purpose of this special study is to determine the best methods for monitoring the optical properties of the water column.
- Incorporate results of tidal phase/slow boat study as modifications to the routine sampling program.
- Evaluate allocation of staff effort to revised EMP and consider adjustments to implementation schedule to ensure a balance between field work, data management, and data analysis and reporting.

E. Year Five:

- Evaluate overall progress with program revisions and identify remaining changes. Prepare an evaluation report and plan for continued implementation and adjustments as appropriate.

IX. References

Apline, A.E. and J.E. Cloern. 1992. Trophic interactions and direct physical effects control phytoplankton biomass and production in an estuary. Limno. Oceanogr. 37:946-955.

Armi, L. 1986. The hydraulics of two flowing layers with different densities: Journal of Fluid Mechanics. 163:27-58.

Armi, L. and D.M. Farmer. 1986. Maximal two-layer exchange through a contraction with barotropic net flow: Journal of Fluid Mechanics. 164:27-51.

Arthur, J, G. Breland, H. Proctor, and H. Gebhard. Committee recommendations from evaluation of the bay-delta continuous water quality monitoring sites. Draft memorandum to California Department of Water Resources (DWR) and Bureau of Relamation (Reclamation) Project Operations and O and M offices. March 12, 1996.

Atwater, B.F., S.G. Conard, J.N. Dowden, C.W. Hedel, R.L. MacDonald, and W. Savage. 1979. History, landforms, and vegetation of the estuary's tidal marshes. Pages 347-385 In T. J. Conomos, [ed]. San Francisco Bay: the urbanized estuary. Pacific Division of the American Association for the Advancement of Science. San Francisco, California, USA.

Burau, J.R., Gartner, J.W., and Stacey, M. 1998. Results from the hydrodynamic element of the 1994 entrapment zone study, Suisun Bay, California. Chapter two in Kimmerer, W.J., (ed). Interagency Ecological Program for the Sacramento-San Joaquin Estuary. Technical Report 56.

Casulli, V. and R.T. Cheng. 1992. Semi-implicit finite difference methods for three-dimensional shallow water flow, Int. J. for numerical methods in fluids. 15: 629-648.

Cheng R.T., V. Casulli, and J.W. Gartner. 1993. Tidal, residual, intertidal mudflat (TRIM) model and its applications to San Francisco Bay, California, Estuarine, Coastal and Shelf Science. 36:235-280.

Cloern, J.E. 1982. Does bentos control phytoplankton biomass in south San Francisco Bay? Marine. Ecol. Progr. Ser. 9:191-202.

Cloern, J.E. 1991. Todal stirring and phytoplantion bloom dynamics in an estuary. Jour. Marine Res. 49:203-221.

DWR [California Department of Water Resources], Office of State Water Project Planning. 2000. Methodology for flow and salinity estimates in the Sacramento-San Joaquin Delta and Suisun Marsh, Twenty-first annual progress report to the State Water Resources Control Board, In accordance with Water Rights Decision 1485, Order 9.

Hollibaugh, J.T. and P.S. Wong. 1996. Distribution and activity of pcterioplankton in San Francisco Bay. Pages 263-288 in Hollibaugh [ed.] 1996. San Francisco Bay the ecosystem: Further investigations into the natural history of San Francisco Bay and Delta with reference to the influence of man. Pacific Divison of the American Association for the Advancement of Science. San Francisco, California.

Hymanson, Z.P., D. Mayer, and J. Steinbeck. 1994. Long-term trends in boenthos abundance and persistence in the upper Sacramento-San Joaquin Estuary. Interagency Ecological Program for the San Francisco Bay/Delta Estuary. Technical report 38. FWQ/BIO/IATR/94-38.

Jassby, A. D., C.R. Goldman, and J.E. Reuter. 2001. Tahoe and the Delta: Some fundamental difference in conservation and restoration issues. IEP Newsletter, 14(3) 18-23.

Jassby A.D., W.J. Kimmerer, S.G. Monismith, C. Armor, J. E. Cloern, T.M. Powell, J.R. Schubel, and T.J. Vendlinski, 1995, Isohaline position as a habitat indicator for estuarine populations. Ecological Applications, Vol. 5: pgs 272-298.

Kimmerer W. and S. Monismith. 1992. An estimate of the historical position of 2 PPT salinity in the San Francisco Bay estuary, report submitted to the San Francisco Estuary Project.

Koseff, J.R., J.K. Holen, S.G. Monismith, and J.E. Cloern. 1993. The effiects of vertical mixing and benthic grazing on phytoplantion populations in shallwo turbid estuaries. Jour. Marine Res. 51:1-26.

Lehman, P.W. 2000. The influence of climate on phytoplankton community biomass in San Francisco Bay Estuary. Limnol. Oceanogr. 45(3) 580-590.

Marple, S.W., 1987, Digital Spectral Analysis with Applications, Prentice-Hall Signal Processing Series, A.V. Oppenheim, ed., Prentice-Hall, New Jersey, 492 pages.

Monismith, S., J.R. Burau, and M. Stacey. 1996. Stratification dynamics and gravitational circulation in northern San Francisco Bay. Pages 123-155 in: J.T. Hollibaugh [ed.] San Francisco Bay the ecosystem: Further investigations into the natural history of San Francisco Bay and Delta with reference to the influence of man. Pacific Divison of the American Association for the Advancement of Science. San Francisco, California.

Monismith, S., J.R. Burau, R. Dinehart, R. Oltmann, C. Ruhl, D. Schoelhammer, and P. Smith. 1998. Hydrodynamics monitoring and reserch. Technical appendix prepared for the CMARP final report. Available at http://www.iep.water.ca.gov/cmarp/groups/ecowt/workplans/hydron1008-6.doc

Mueller-Solger, A., A.D. Jassby, and D. Muller-Navarra. In preparation. Nutritional value of particulate organic matter for zooplankton (*Daphnia*) in a tidal freshwater system (Sacramento-San Joaquin River Delta, USA).

Schemel L. 2001. Simplified conversions between specific conductance and salinity units for use with data from monitoring stations. IEP Newsletter 14(1) 17-18.

Sobczak, W.V., J.E. Cloern, A.D. Jassby, and A.B. Mueller-Solger. In preparation. Bioavailability of organic matter in a highly discrubed estuary: Implications for ecosystem restoration.

Stearns, S.D. and R.A. David, 1988, Signal Processesing Algorithms, Prentice-Hall Signal Processing Series, A.V. Oppenheim, ed., Prentice-Hall, New Jersey, 349 pp.

SWRCB [State Water Resources Control Board]. 1995. Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. 45 pages.

Thompson, B., S. Ogle, C. Foe, T. Barry, R. Geryason, K. Kuivila, and S. Luoma. 1998. Contaminants Monitoring in the Bay-Delta. Technical appendix prepared for the CMARP final report. Available at http://www.iep.water.ca.gov/cmarp/groups/wqwt/workplan/bdcontam1102.doc

Table1: Information Needs

Present information needs	Currently monitored constituents	Current method and data compatibility with other programs	Current customers	Current customer satisfaction (Are needs met? Efficiently?)	Recommendations for maintaining or improving customer satisfaction	Related future information needs and potential customers
1. Monitor to assess compliance with SWRCB salinity objectives listed in the Bay-Delta Water Quality Control Plan (SWRCB, 1995).[8]	Continuous EC measurements at specific locations; X2 position; chloride levels	Primary method is continuous monitoring of EC at fixed stations. Methods and data are highly compatible with other programs.	SWRCB, DWR and USBR Operations, DFG, FWS, Calfed, Contra Costa Water Dist., Env. and water user stakeholders	Yes needs are generally met, although efficiency gains are likely through increased coordination/ integration of existing monitoring sites with those operated by USBR and USGS	Improve/expand web-based site for one-stop shopping of EC data and USGS flow measurements	Water project operators would like information on salt field dynamics and changes over time. This would mean more directly relating EC and flow measurements.
2. Monitor to assess compliance with SWRCB dissolved oxygen objective listed in the Bay-Delta Water Quality Control Plan (SWRCB, 1995).[9]	Continuous and discrete measures of dissolved oxygen and water temperature.	Both continuous monitoring at a fixed station and more intensive discrete monitoring on a seasonal basis. Methods and data are compatible with other programs.	SWRCB, DWR, USBR, DFG, CVRWQCB, Calfed, City of Stockton, Env. and water user stakeholders	The need to assess compliance with the SWRCB water quality objective is being met. However, more recent interest in source and solution to seasonally low DO levels in the Stockton Deepwater Ship Channel have resulted in more intensive study and monitoring of this area. There is some customer concern about monitoring data quality.	Continue continuous and seasonally focused discrete monitoring. Add a bottom DO sensor at the continuous monitoring site. Work with customers to ensure data quality.	May need to increase continuous monitoring network over a select area of the San Joaquin River to assess results and compliance with a TMDL regulation for DO.

[8] Water quality objectives for salinity and chloride are included for the reasonable protection of the following beneficial uses: 1) Municipal and Domestic Supply; 2) Industrial Service Supply; 3) Industrial Process Supply; 4) Agricultural Supply; and 5) Spawning, reproduction, and/or early development. The fifth beneficial use relates to salinity objectives for the lower San Joaquin River "to protect striped bass spawning habitat."

[9] A water quality objective for dissolved oxygen levels in the San Joaquin River is for the reasonable protection of the migration of aquatic organisms. Specifically, "a dissolved oxygen objective is included to protect fall-run salmon migration in the lower San Joaquin River" (SWRCB, 1995).

Present information needs	Currently monitored constituents	Current method and data compatibility with other programs	Current customers	Current customer satisfaction (Are needs met? Efficiently?)	Recommendations for maintaining or improving customer satisfaction	Related future information needs and potential customers
3. Document status and trends in physicochemical conditions in the upper estuary. This information is used to: 1) aid our understanding of the effects water quality conditions have on ecosystem functions and processes; 2) provide input to the planning and operation of large-scale engineered facilities and habitat restoration projects; and 3) develop hypotheses to explain the processes underlying the observed patterns and trends in the monitoring data. These hypotheses are tested through special studies.	water temperature, turbidity, dissolved oxygen, macro-nutrients, secchi disk depth, conductivity. Wind speed and direction, solar radiation, air temperature, water elevation, and pH are measured discretely or continuously at several locations in the upper estuary. See Figure 16 for station locations and Table 4 and 5 for constituent details.	Generally Standard Methods are used for the collection of discrete samples. Continuous monitoring data are collected at fixed shore-based stations using electronic sensors	All CALFED agencies, agricultural, municipal, and industrial users of the Estuary, environmental stakeholders, and the general public	No, customers are not satisfied. There is growing concern that the consistency of the program has declined threatening the continuity of the long-term records. There is also concern that the program has not been responsive to increases in our understanding of the system and the need to fill gaps in knowledge. There is an ongoing tension between the general nature of the monitoring program to meet the need of a baseline monitoring program and changes in program emphasis to address more specific, often short-term needs. Many customers are dissatisfied with the inaccessibility of the data and slow transfer of data into information.	Do a better job of educating customers of the needs this monitoring program is able to meet. Increase the use of web-based data dissemination and reporting tools. Re-examine the monitoring program design based on our current conceptual understanding of the system and the processes driving change. Need to carefully evaluate the use and relationship of discrete Versus continuous sampling of various constituents.	Expand the network of continuous water temperature monitoring. This information is useful to understanding and predicting fish spawning events and growth rates. All customers could benefit from this. Explicitly relate monitoring data to land use patterns and changes over time. Initial efforts should use existing aerial surveillance information. All customers could benefit from this. Make better use of web-based reporting tools and data dissemination capabilities.

Present information needs	Currently monitored constituents	Current method and data compatibility with other programs	Current customers	Current customer satisfaction (Are needs met? Efficiently?)	Recommendations for maintaining or improving customer satisfaction	Related future information needs and potential customers
4. Provide continuous physicochemical data for use in the development and calibration of models.	Electrical conductivity (EC) and water elevation (stage)	continuous data collected from fixed, shore-based stations. Continuous data are reported every 15 minutes or every hour depending on the site. The methods are very compatible with other programs.	DWR, USBR, USGS, SWRCB, and Calfed, academic scientists and researchers, stakeholders	EC and stage data meets many customer needs. There is concern regarding the representativeness of the data, particularly downstream of X2. There is redundancy in sampling locations with other DWR and USBR programs particularly in the Delta. There is a potential for a dramatic increase in efficiency and cost savings if the various programs were combined appropriately. Sampling methods, verification, and calibration procedures do differ and may reduce compatiblity of data.	Consider lateral and vertical variability in EC, particularly downstream of X2. Expand sensor array where lateral and vertical variability is a concern (e.g., Carquinez Strait, Suisun Bay). Expand the network of continuous water temperature monitoring.	Development of a model to understand the water clarity/light dynamics in the Delta and the role it plays in primary production

Table for Proposed New or Revised EMP Monitoring Activities (Including short-term methods evaluations) for the Water Quality Monitoring Element

Priority NO.	Monitoring Activity	Information Need Addressed	Justification	Staff Need	Other Resource Needs	Implementation start date (year) or period
N/A in progress	EMP data management and reporting	Timely public availability of accurate monitoring data and reporting of EMP information (data to information).	A monitoring program is of little value if the data are not made available or the data are not analyzed to extract relevant information.	50% of one ES III 15% of one WREA and two ES I	Dedicated server, consultant time for software development and web based reporting tools, GIS and spatial analysis software	Started 2001 ongoing task
1	Begin discrete sampling on alternating spring/neap tides	Provides a method for collecting more representative discrete samples	Reduces biases associated with variability arising from the spring-neap cycle	No additional staff is needed to develop a sampling schedule, but field work may be increased by an undetermined amount due to some loss in sampling flexibility	None	Year one (2003)
2	Discontinue discrete monitoring at station C3 and C10 (van run), and station P8 (boat run). Initiate collection of discrete samples at continuous monitoring stations, 15, 22, and 21 respectively. Add a near-bottom DO and temperature sensor at station P8.	Documentation of basic water quality conditions in the Sacramento and San Joaquin rivers.	Comparative data analysis shows no reduction in the ability to document local water quality conditions. The continuous data stream is considered superior to discrete monitoring of basic water quality conditions. Staff and resource savings from combining discrete and continuous sites will be applied to other areas within the program.	No additional staff needed. Some training of CST I/II staff maintaining continuous sites to ensure proper collection and storage of discrete samples.		Year one (2003)

Table for Proposed New or Revised EMP Monitoring Activities (Including short-term methods evaluations) for the Water Quality Monitoring Element, cont.

Priority NO.	Monitoring Activity	Information Need Addressed	Justification	Staff Need	Other Resource Needs	Implementation start date (year) or period
3	Establish CT sensors at proposed stations 1-8. Continue duel operation of sensors at station 5 to test lateral variability	Monitor locations in San Pablo and Suisun Bays associated with gravitational circulation (i.e., sills and cells). Establish sensors in center channel near Martinez to permit more representative sampling of the water column and determine if lateral variability is significantly affecting measurements at the shore-based station	This sampling design better accounts for temporal and spatial variability in salinity and water temperature at all time scales. This design also places sensors in or near the center channel permitting the collection of more representative data	100% of two CST I/II and 50% of one boat operator during station installation (six months) 25% of one CST I/II and one boat operator for stations maintenance	CT sampling equipment and associated hardware. Dedicated boat, foul weather gear	Year one (2003)
4	Modify continuous monitoring station 17 (existing station 80) from seasonal to year-around operation	Provides year-around continuous monitoring of basic water quality conditions in the central delta	More intensive monitoring in this region of the central delta will allow better assessment of water quality conditions in relation to beneficial uses. Year-around operation of this station would also obviate the need for discrete monitoring station D26 allowing reallocation of staff and resources to other efforts.	20% of Sr. CSE for planning and permitting associated with establishment of a new station house. 5% of CST I/II year-around for station maintenance	Depending on siting of new station house \$50,000 - \$75,000 may be required for construction of a new station.	Year one (2003)

Table for Proposed New or Revised EMP Monitoring Activities (Including short-term methods evaluations) for the Water Quality Monitoring Element, cont.

Priority NO.	Monitoring Activity	Information Need Addressed	Justification	Staff Need	Other Resource Needs	Implementation start date (year) or period
1	Replace annual data report with web-based reporting tools and "status and trends" report in IEP Newsletter	Timely and broad-based availability of basic information. Streamline reporting requirements improving ability to remain current	Value of the monitoring program is greatly increased if timely information is made available to the broadest audience	50% of one ES III, 25% of three ES I/II year-around	consultant time for software development and web based reporting tools, GIS and spatial analysis software	Year two (2004)
2	Increase number of discrete sampling stations from 11 to 18. Begin discrete sampling at stations 2, 3, 5, 6, and 10-22. Collect discrete samples during continuous station maintenance or as part of the zooplankton or benthos sampling. Constituents sampled would depend on continuous instrumentation.	This expansion of discrete sampling effort is intended to provide better spatial coverage of sampling sites and sample under-represented habitat types (e.g., shallow subtidal, open-water habitats).	The existing number of discrete sampling sites is not adequate given the spatial heterogeneity and habitat diversity in the upper estuary. This strategy of expanding discrete sampling sites at continuous monitoring locations is intended to minimize additional field staff efforts while maximizing the information gained. Further, discrete sampling of some constituents that are also sampled continuously provides an important form of quality control	Depending on exact implementation, we expect a 20% increase in staff field time. Assuming two staff this would equate to 4 staff days per month.	Some sample storage or collection equipment may be required to deal with sample collection and transit.	Year two (2004)
1	Evaluate allocation of staff effort to revised EMP and consider adjustments to implementation schedule to ensure a balance between field work, data management, and data analysis and reporting	Formal reality check to ensure complete implementation is occurring in the most efficient manner.	Implementation of numerous changes to a multifaceted program is difficult. Adjustments will neeed to occur along the way	20% time of two ES and two supervisors for over one year.	None	Year four (2007)

Table for Proposed Special Studies (to be funded by EMP, IEP, or other sources) for the Water Quality Monitoring Element

Priority NO.	Special Study	Information Need Addressed	Justification	Staff Need	Other Resource Needs	Implementation start date (year) or period
1	Initiate a study to determine what the spatial distribution for a network of continuous water temperature sensors.	Continuous measurement of water temperature within the delta and suisun marsh. Combined with fish and zooplankton sampling data water temperature information can be used to predict the time of spawning, development, and growth of zooplankton and fishes.	Monitoring the spatial and temporal changes in water temperature will provide important environmental information useful in: 1) understanding the life history patterns of important species; 2) the development of deterministic models; and 3) the real-time management of project operations	One ES III or IV 30% for one year and two Sci aids 100% time for one year	Onset temperature loggers; portable computer; one boat	Year one (2003)
1	Initiate interagency (DWR, USBR, and USGS) review of upper estuary continuous monitoring network	Investigations have shown there is substantial duplication in the continuous monitoring networks operated by DWR and USBR. USGS monitoring of flow and stage is generally not duplicative, but may benefit from more strategic location and integration with DWR and USBR network. Finally, standard operating procedures are needed for DWR and USBR continuous monitoring.	Reduction of continuous monitoring network redundancy could generate substantial efficiencies among agency programs. Network integration could also result in more straightforward data reporting. Standard operating procedures will provide more comparable data.	One EPM I 10% and one Sr. CSE 20% for one year. Time for USBR and USGS staff is also needed.	None	Year two (2004)

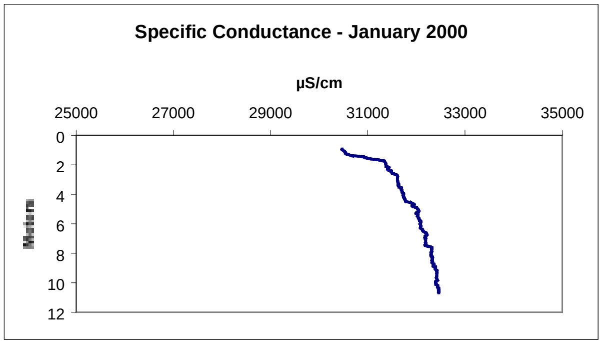
Table for Proposed Special Studies (to be funded by EMP, IEP, or other sources) for the Water Quality Monitoring Element, cont.

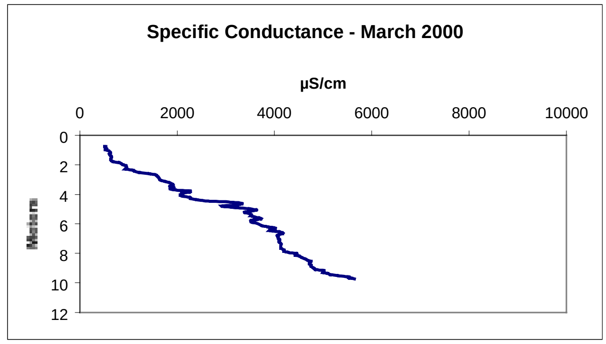
Priority NO.	Special Study	Information Need Addressed	Justification	Staff Need	Other Resource Needs	Implementation start date (year) or period
2	Two-year, pilot monitoring of BOD, size-fractionated chlorophyll a, and continuous flow and in vivo chlorophyll a fluorescence, at stations 9 and 22.	Measurements of BOD, size-fractionated chlorophyll a will inform us about the amount of total labile carbon and the quality of the food entering the delta. Continuous flow and in vivo chlorophyll a measurements will allow calculation of the phytoplankton flux at two major inflow stations (Sacramento River and San Joaquin River)	Monitoring these constituents in a coordinated way will provide information that can improve our understanding of delta food web dynamics and how the foundation of the food web changes over time.	30% of two USGS techs. For 3 months to establish ADCP equipment at station 22. 20% of one CST I/II for two weeks to establish a fluorometer at station 9. 5% more staff time during discrete sample collection.	Fluorometer, ADCP, may be some additional lab costs for BOD sample analysis	Year two (2004) evaluate in year four (2006)
1	Special study to evaluate sampling bias associated with tidal phase aliasing – the "slow boat" effect	The EMP has historically addressed tidal time scale variability by sampling at a fixed phase of the tide –high water slack tide. This provides a "snap shot" of water quality conditions at a certain tidal phase. The boat used to collect discrete samples travels at about ½ the speed of the tide-wave propagation speed. This means not all samples are collected at the same tidal phase. A quantitative evaluation of the "slow boat" effect will permit an objective evaluation of this issue.	Sampling over changing tidal phases introduces a from of aliasing into the discrete data that should be accounted for. It may be that no boat is able to reach sampling stations in the delta at the same point on the tide due limitations in operating a vessel in public waters. However, a quantitative evaluation will at least allow documentation of the issue.	Two boat operators and four ES for two field days each season over one year. 20% time of one ES to manage and analyze the resulting data.	Requires two existing boats and associated discrete sampling equipment.	Year three (2005)
1	Evaluate methods for monitoring water clarity and light transmittance	Which optical properties of the water column should be measured to maximize our understanding of how changes in water clarity/light transmittance affects primary production	Light limits algal growth in the upper estuary and is major cause of phytoplankton variability.	One ES 25%, one scientific aid full time. Post-graduate researcher with expertise in physical limnol.	Monitoring equipment (e.g., radiometers, turbidimeters, etc.)	Year four (2006)

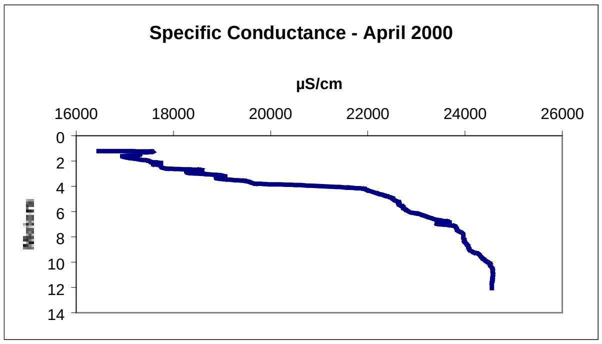
APPENDIX A

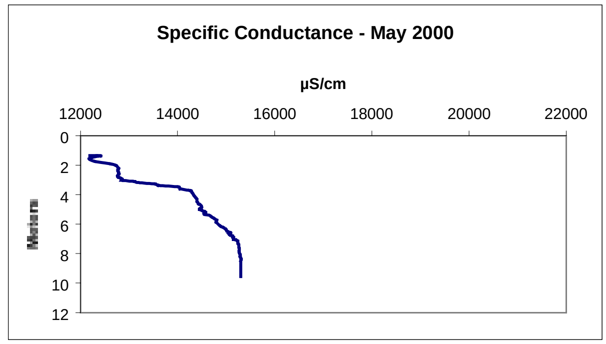
Monthly Vertical Profile Plots of conductivity and water temperature for Discrete Stations: D6, D4, D28A, and P8.

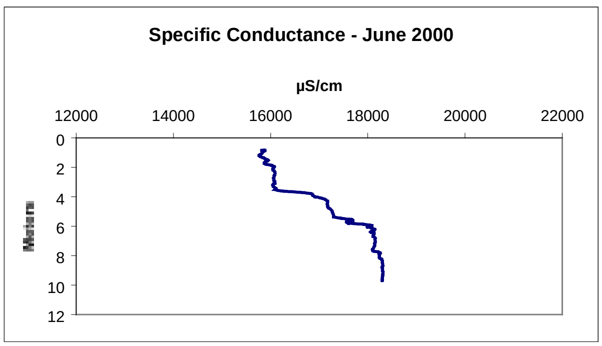
Specific Conductance (µS/cm) Vertical Profiles for Discrete Station D6 - 2000
Graphs scaled at 10,000 µS/cm

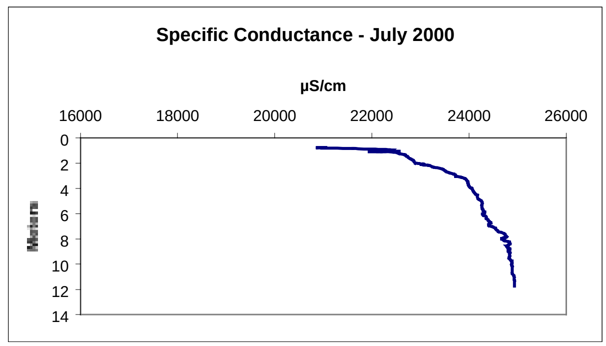












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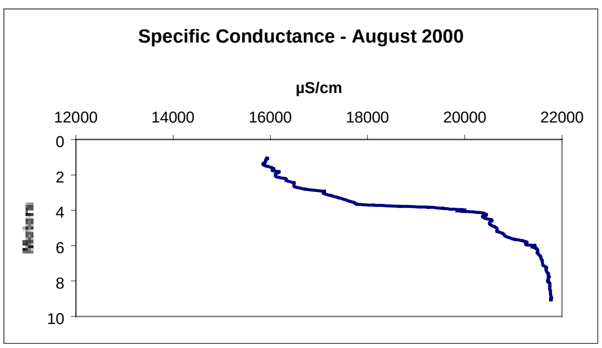
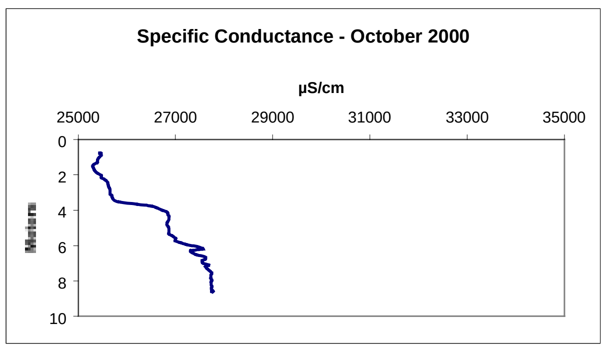
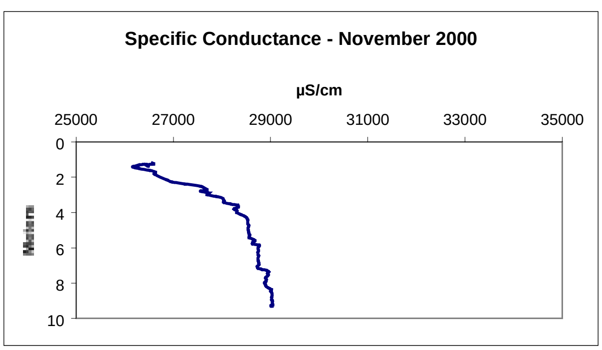


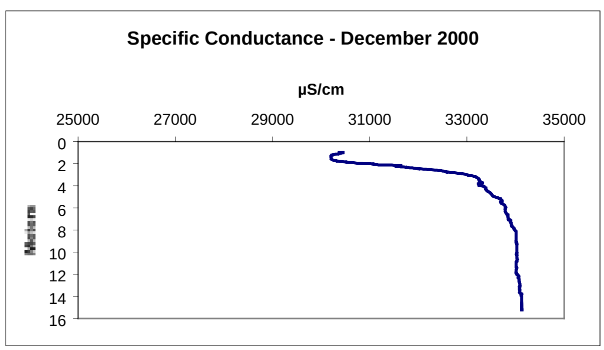
Specific Conductance - August 2000
µS/cm
12000
14000
16000
18000
20000
22000
0
2
4
6
8
10



Specific Conductance - October 2000
µS/cm
25000
27000
29000
31000
33000
35000
0
2
4
6
8
10

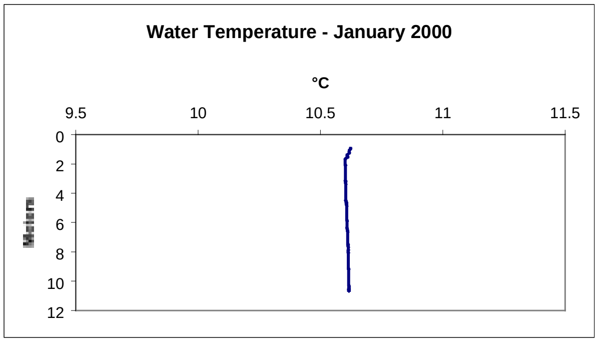


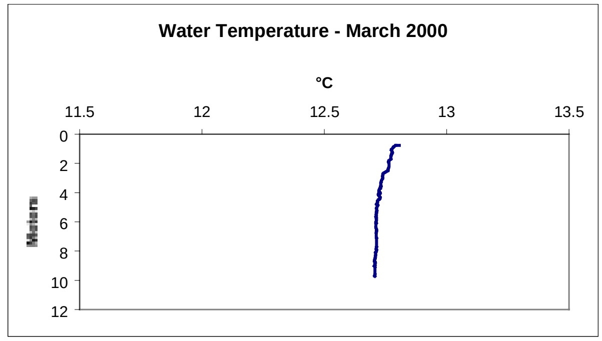
Specific Conductance - November 2000
µS/cm
25000
27000
29000
31000
33000
35000
0
2
4
6
8
10

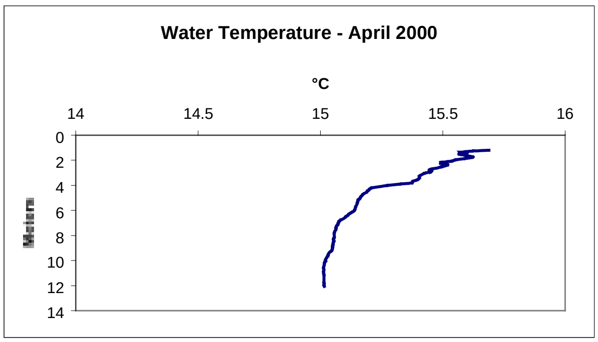


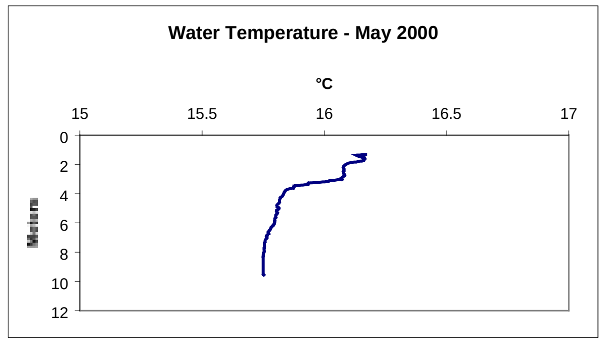
Specific Conductance - December 2000
µS/cm
25000
27000
29000
31000
33000
35000
0
2
4
6
8
10
12
14
16

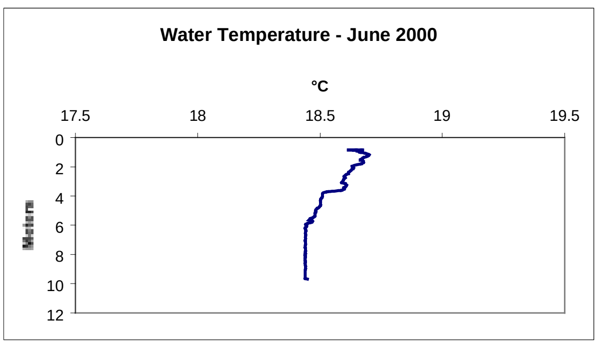
Water Temperature (°C) Vertical Profiles for Discrete Station D6 - 2000
Graphs Scaled at 2 °C

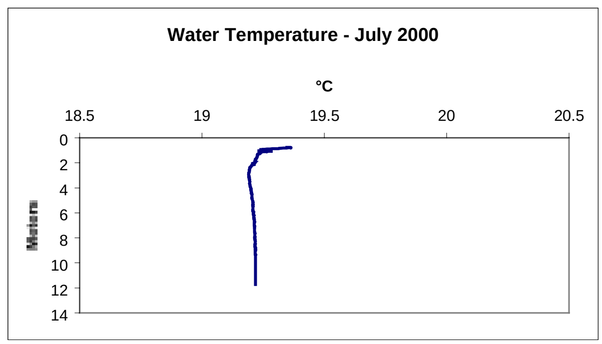


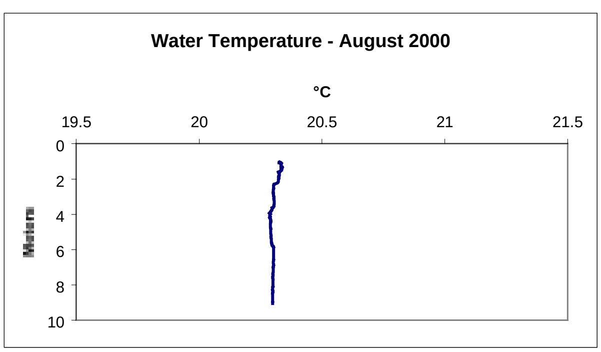


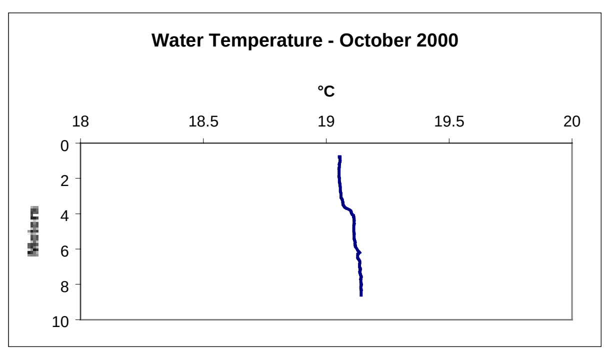


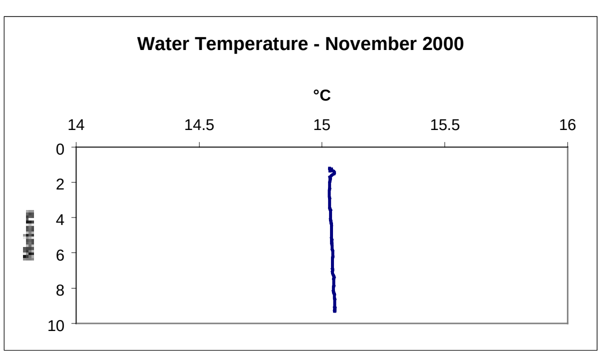


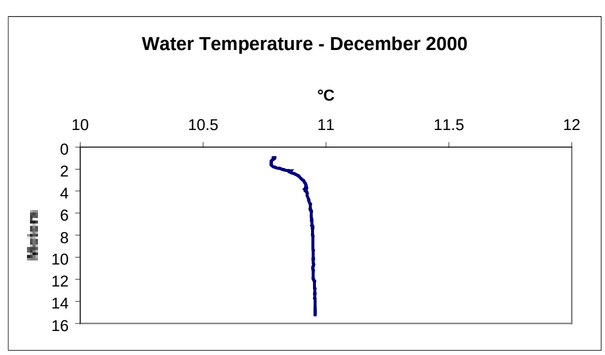






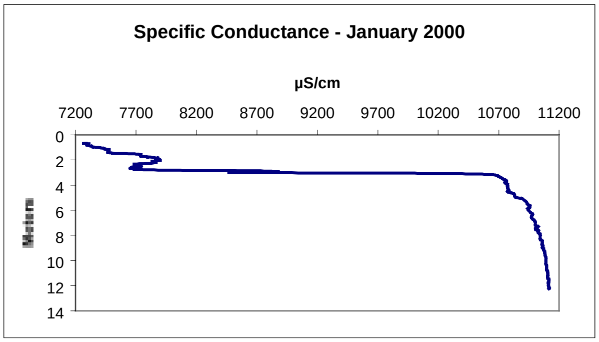


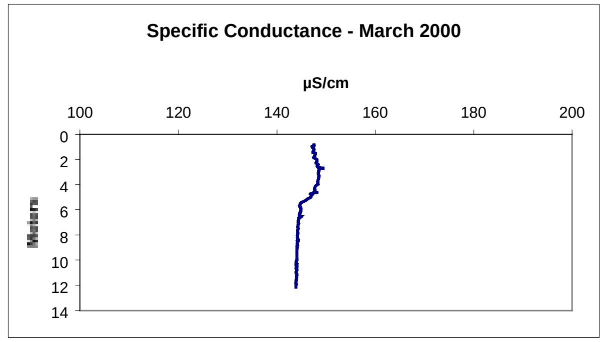


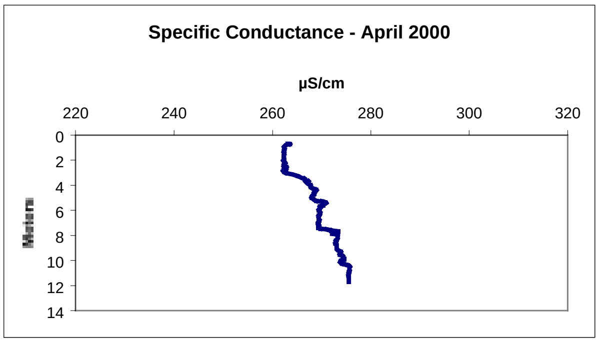


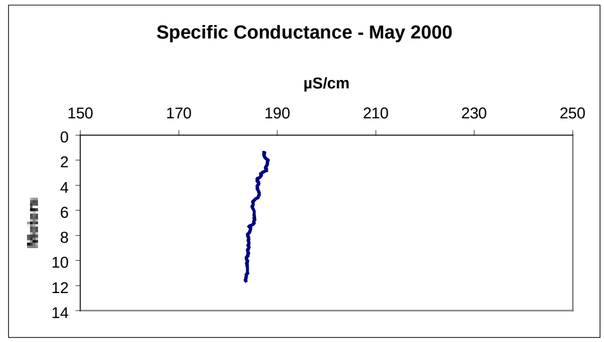
Specific Conductance (µS/cm) Vertical Profiles for Discrete Station D4 - 2000

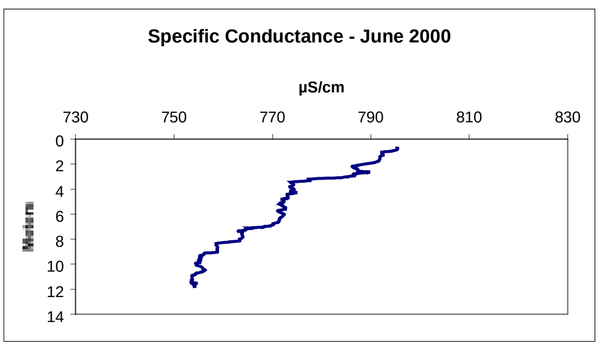
Graphs scaled at 100 µS/cm, except January, October, November, and December at 4000 µS/cm

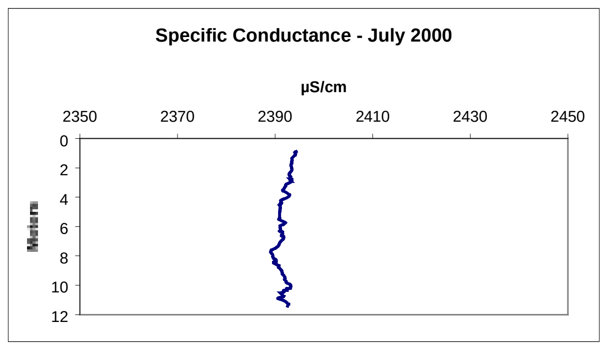


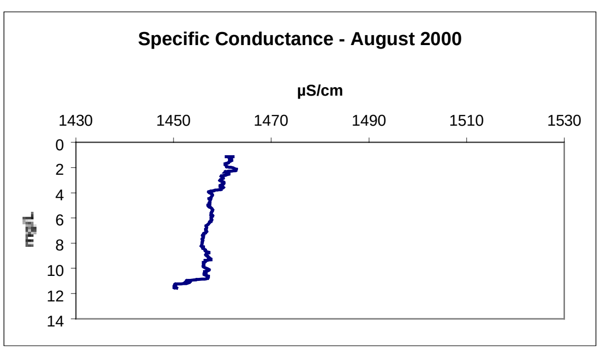


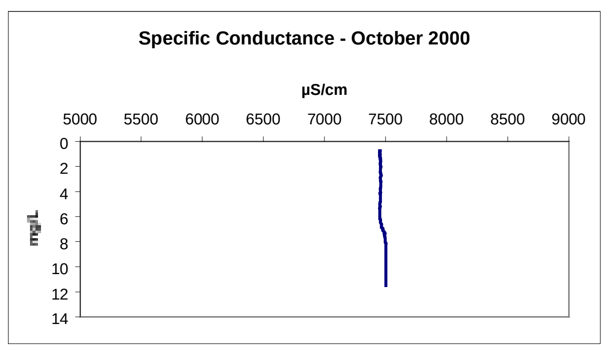


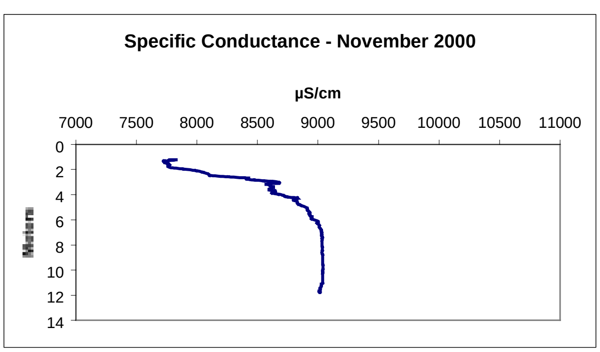


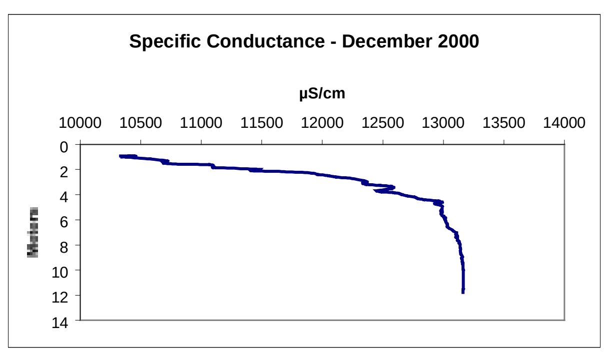






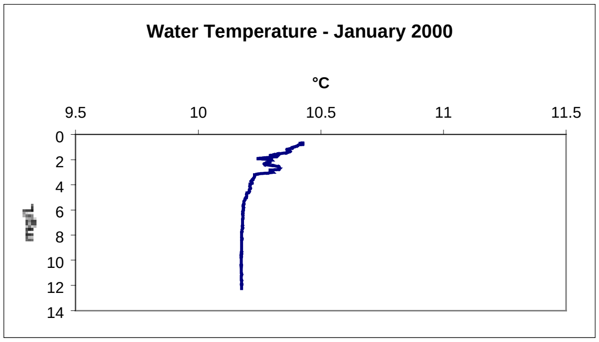


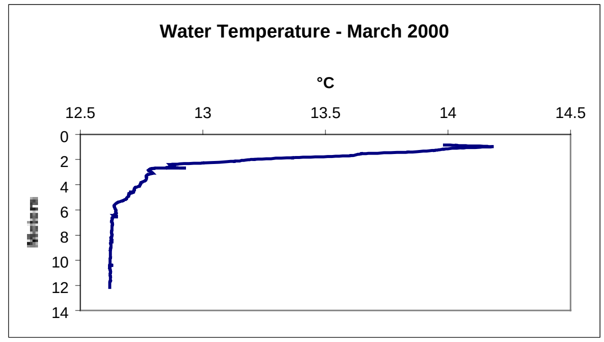


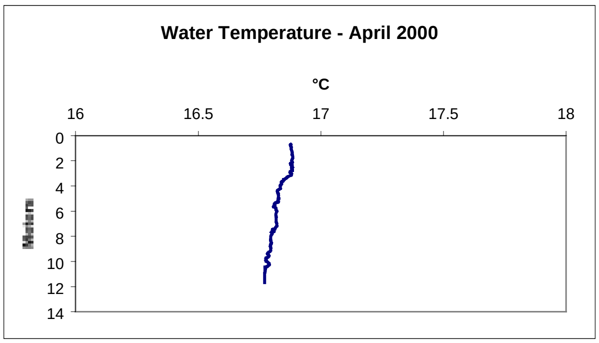


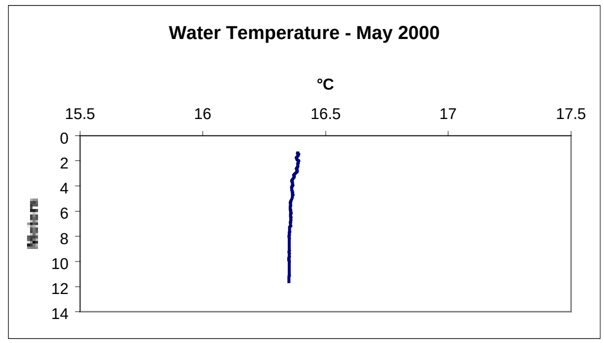
A3

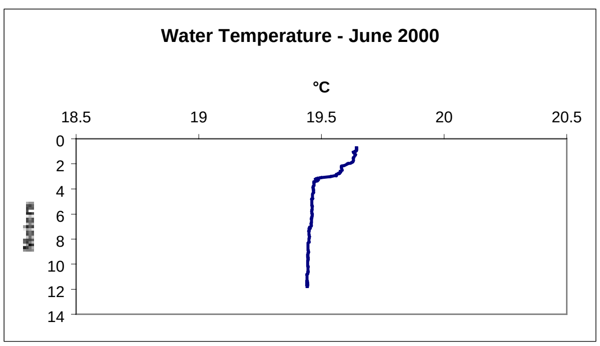
Water Temperature (°C) Vertical Profiles for Discrete Station D4 - 2000
Graphs scaled at 2 °C

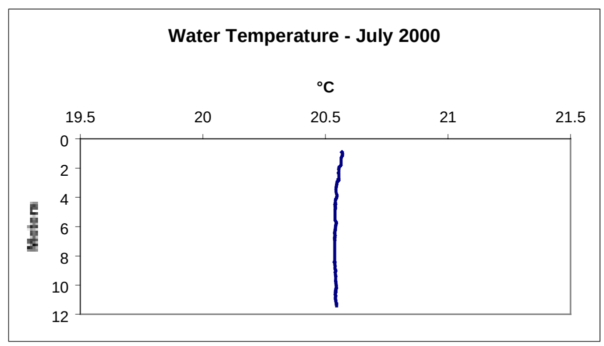


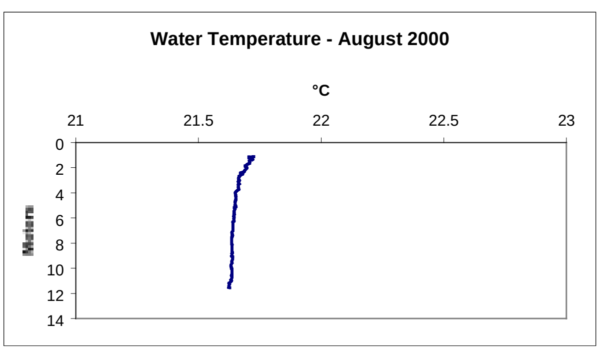


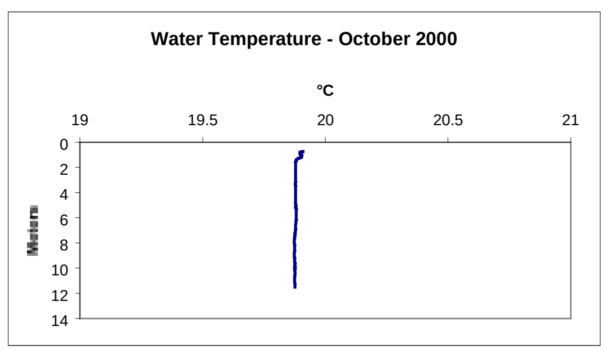


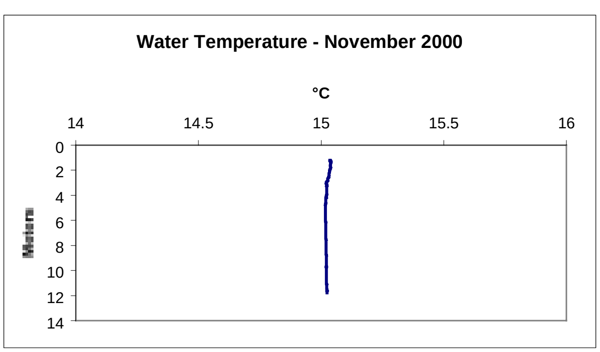


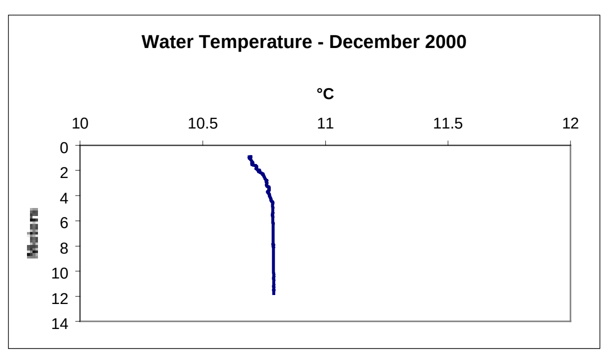








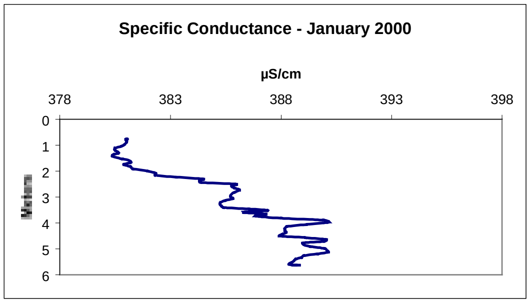


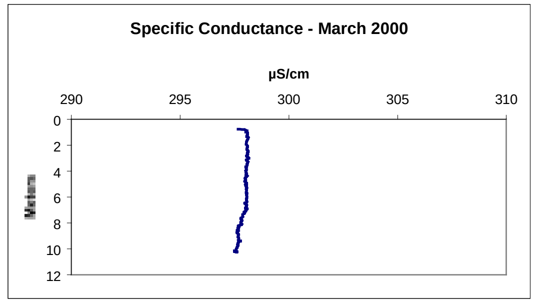


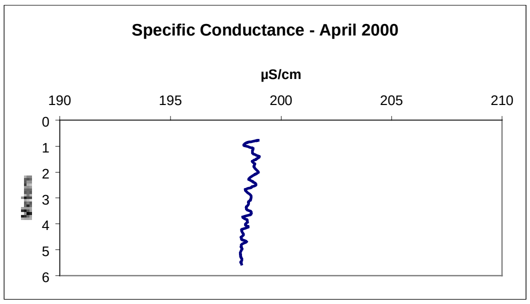
A4
A5

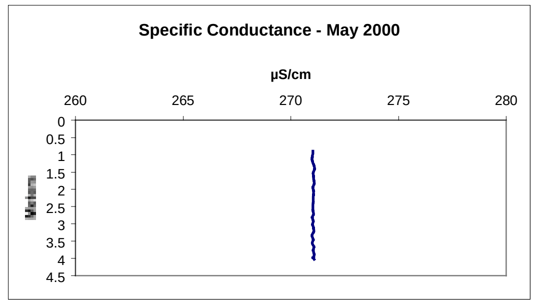
Specific Conductance (µS/cm) Vertical Profiles for Discrete Station D28A - 2000

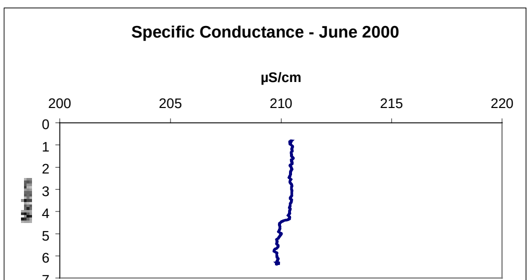
Graphs scaled at 20 µS/cm

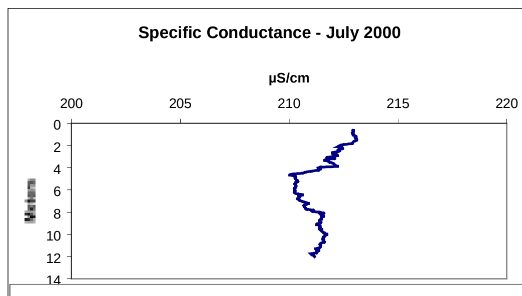


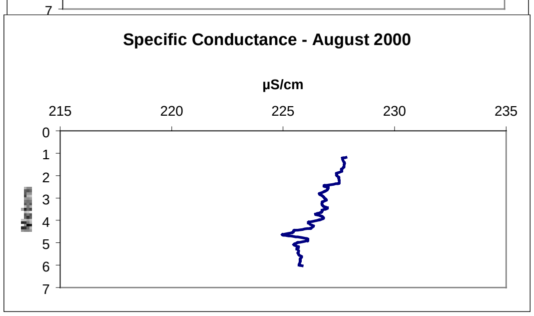


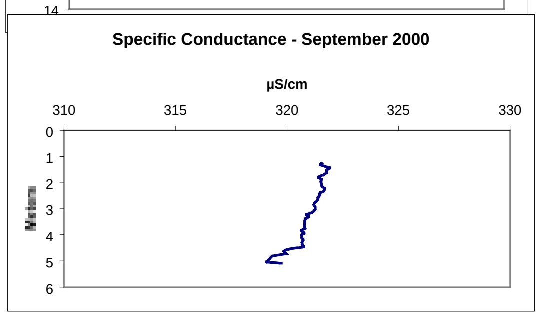


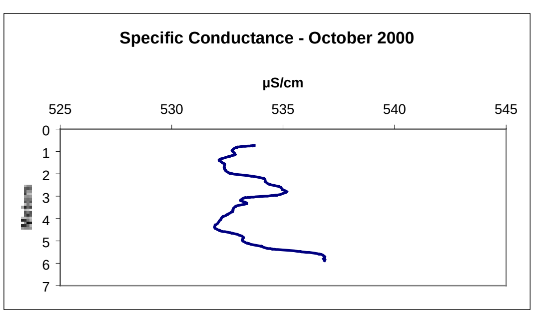


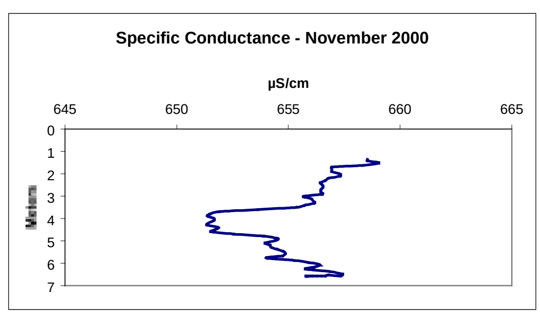


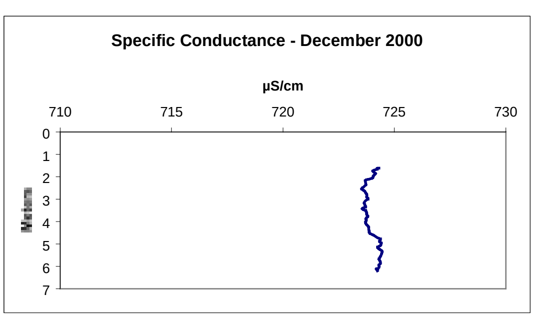




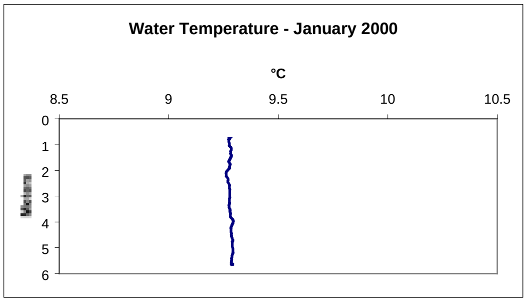




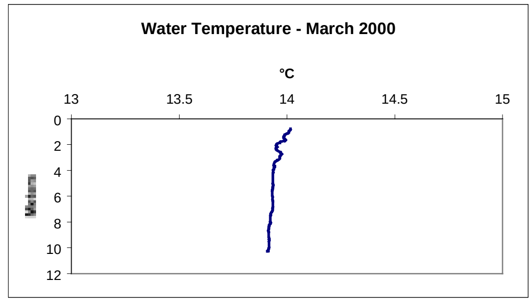




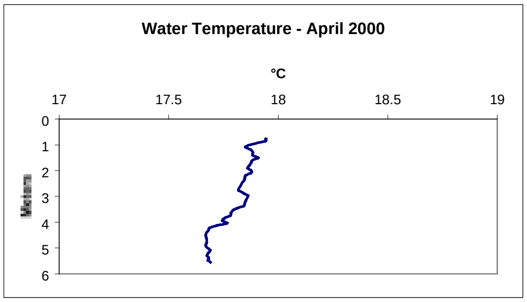
Water Temperature (°C) Vertical Profiles for Discrete Station D28A - 2000
Graphs scaled at 2 °C



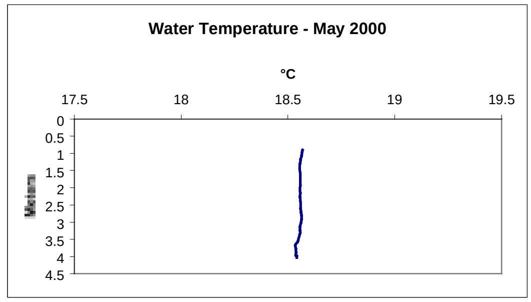
Water Temperature - January 2000



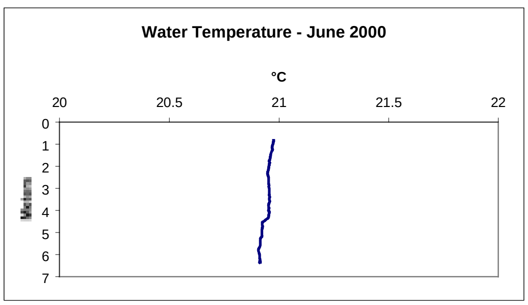
Water Temperature - March 2000



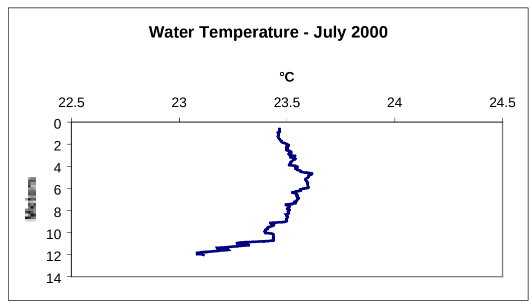
Water Temperature - April 2000



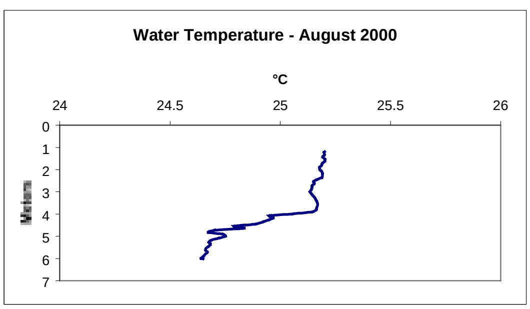
Water Temperature - May 2000



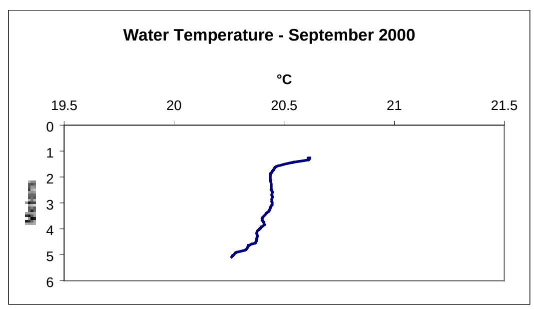
Water Temperature - June 2000



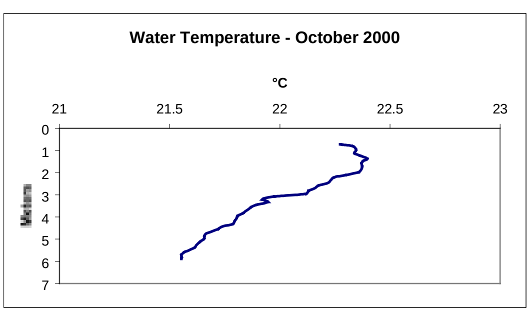
Water Temperature - July 2000



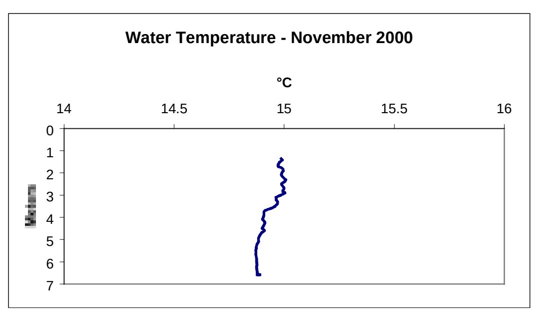
Water Temperature - August 2000



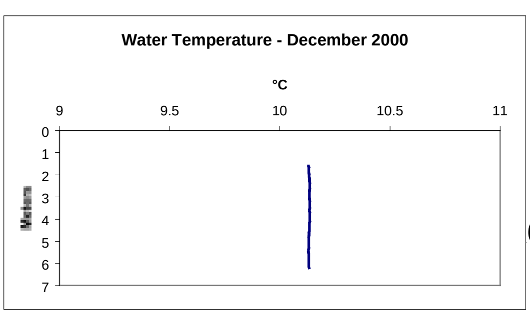
Water Temperature - September 2000



Water Temperature - October 2000

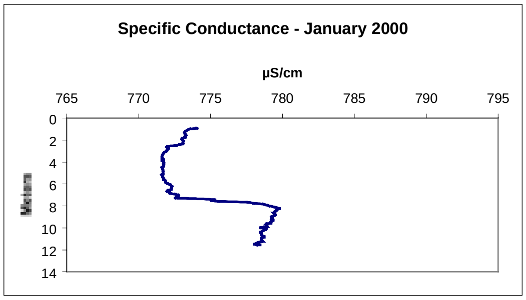


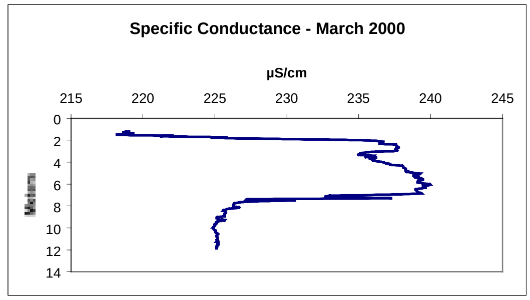
Water Temperature - November 2000

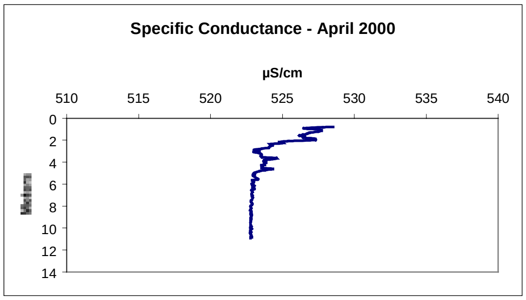


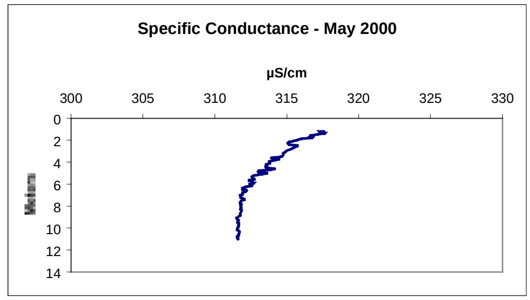
Water Temperature - December 2000

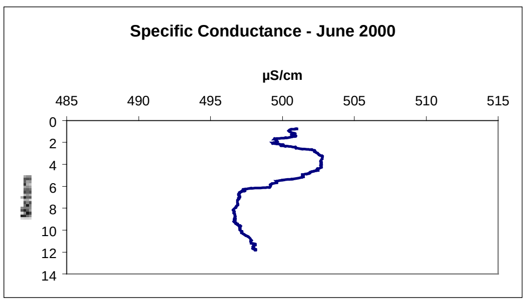
Specific Conductance (µS/cm) Vertical Profiles for Discrete Station P8 - 2000
Graphs scaled at 30 µS/cm

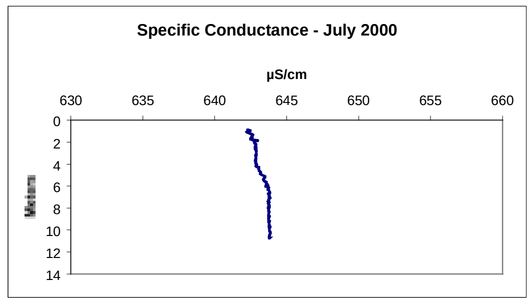


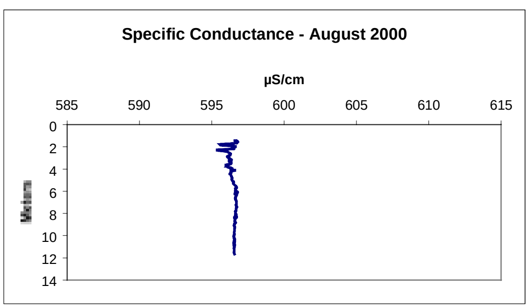


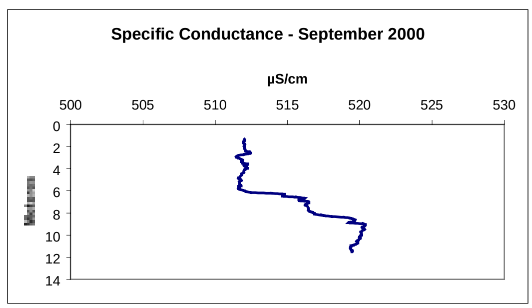


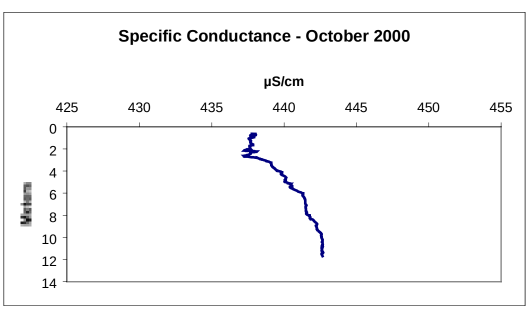


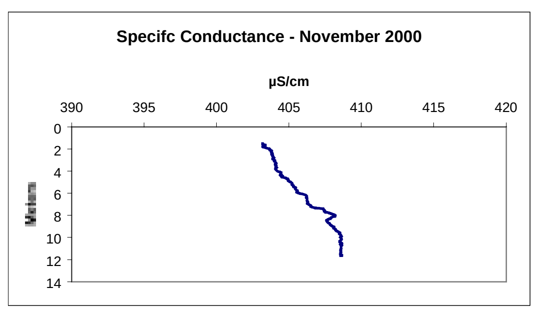


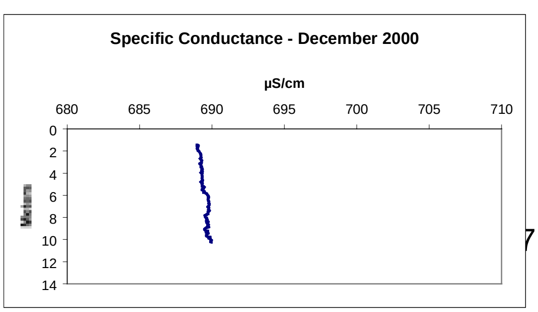






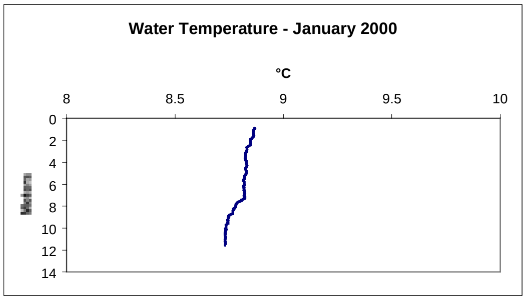


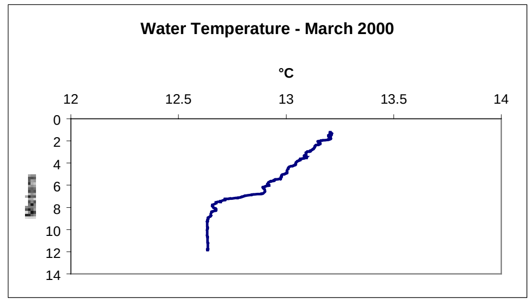


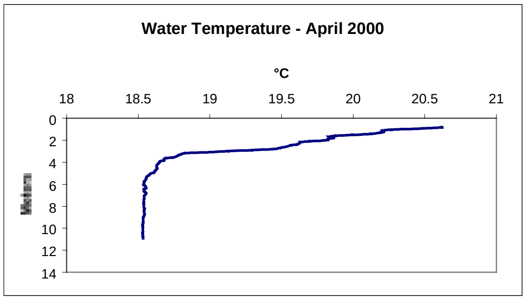


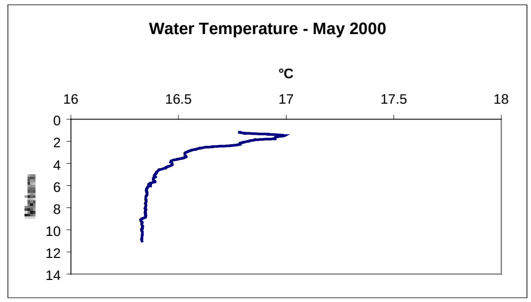
Water Temperature (°C) Vertical Profiles for Discrete Station P8 - 2000

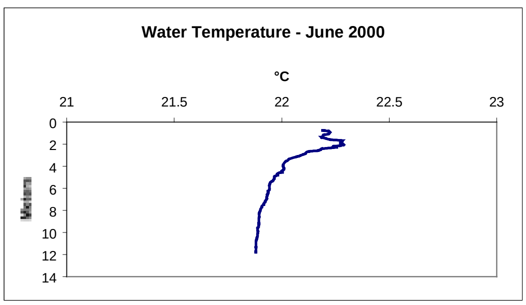
Graphs scaled at 2 °C, except April (3 °C)

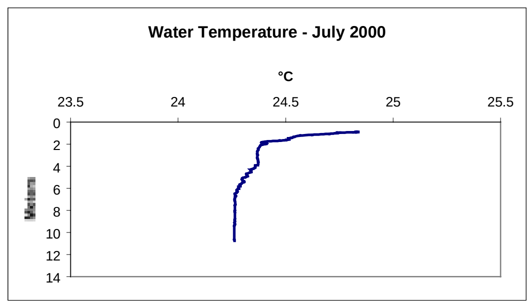


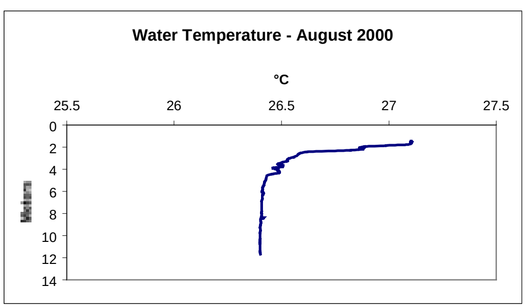


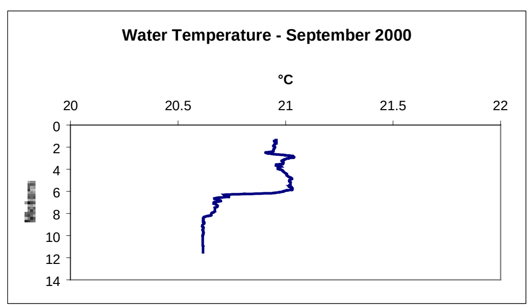


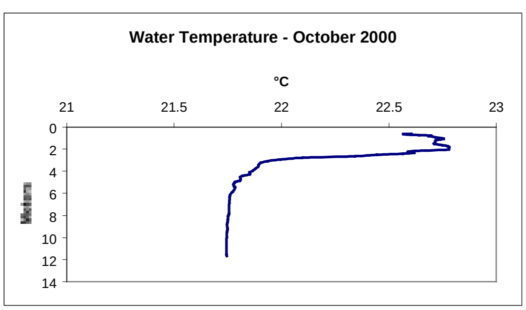


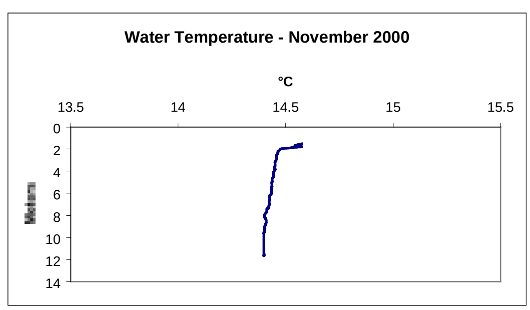


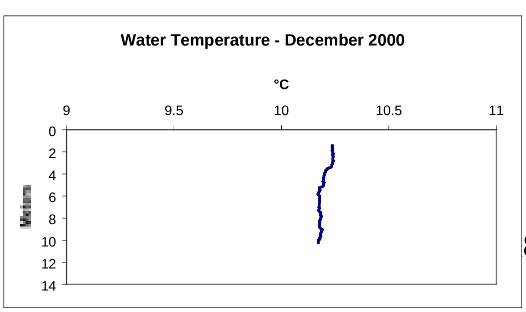








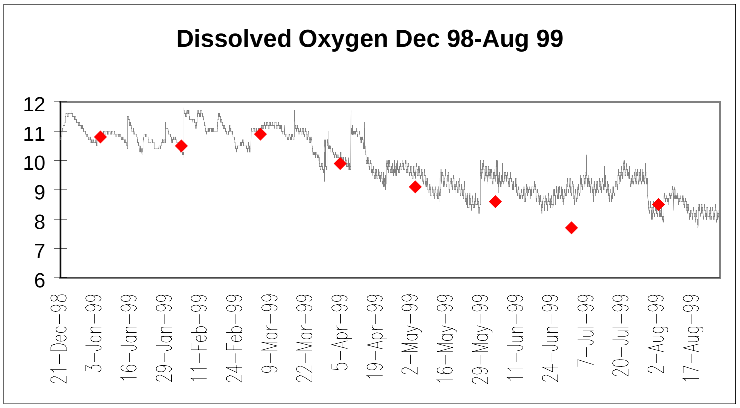


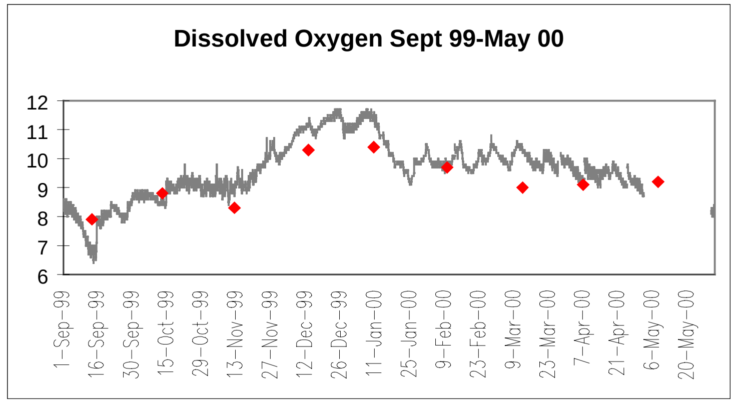


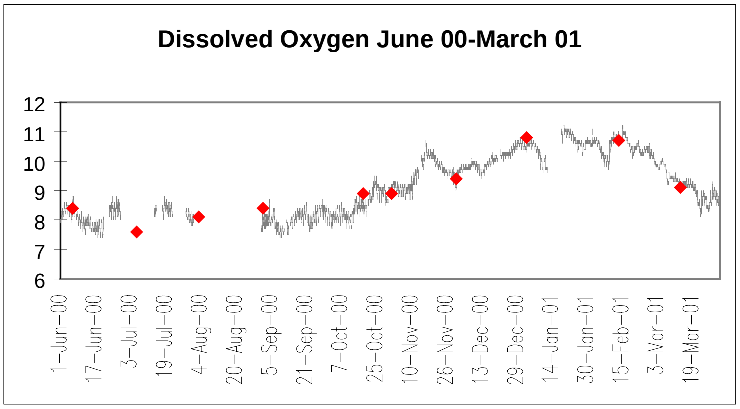
APPENDIX B

Plots comparing discrete and continuous measurements of dissolved oxygen, conductivity, water temperature and pH and Corresponding Regression Analysis for several stations in the delta

Dissolved Oxygen (mg/L) for Discrete Station C3 and Continuous Monitoring Station 70
December 1998 – March 2001

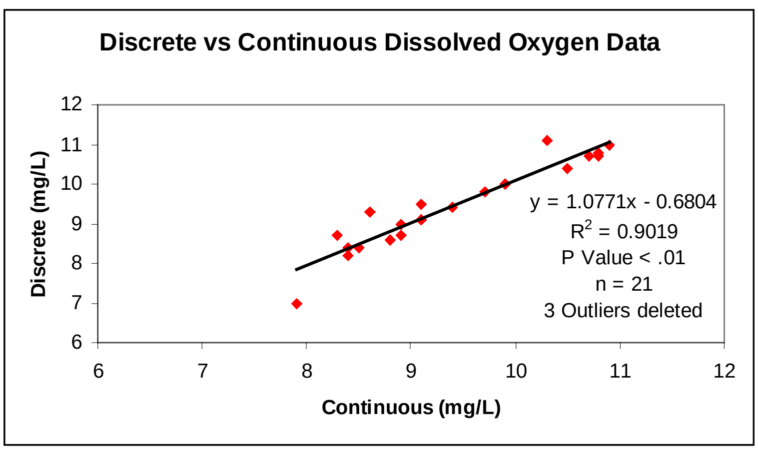






Continuous

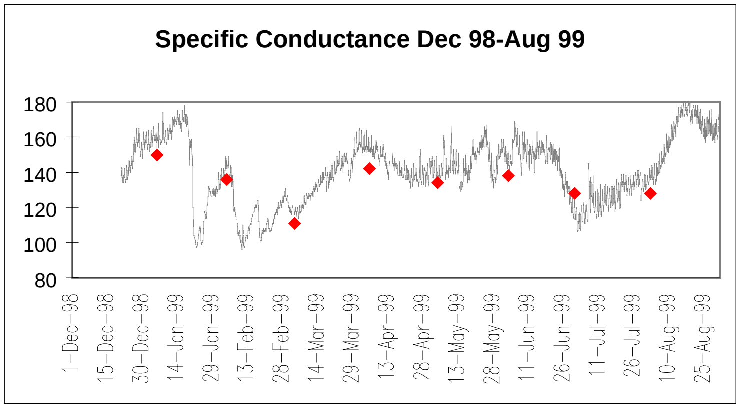
◆ Discrete

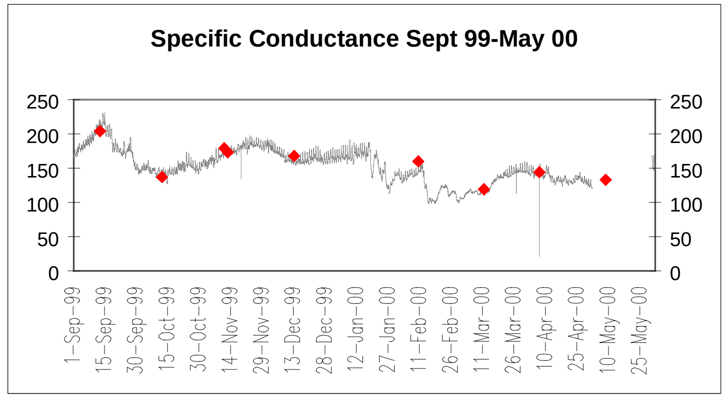


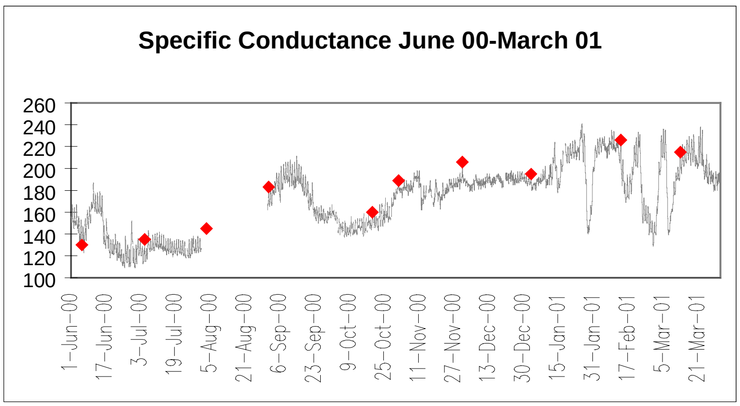
Absolute Difference Discrete - Continuous	
Mean	-0.04
Standard Deviation	0.35
Minimum	-0.8
Maximum	0.9

Residuals	
Standard Deviation	0.3
Minimum	-0.68
Maximum	0.55

Specific Conductance (µS/cm) for Discrete StationC3 and Continuous Monitoring Station 70 December 1998 – March 2001

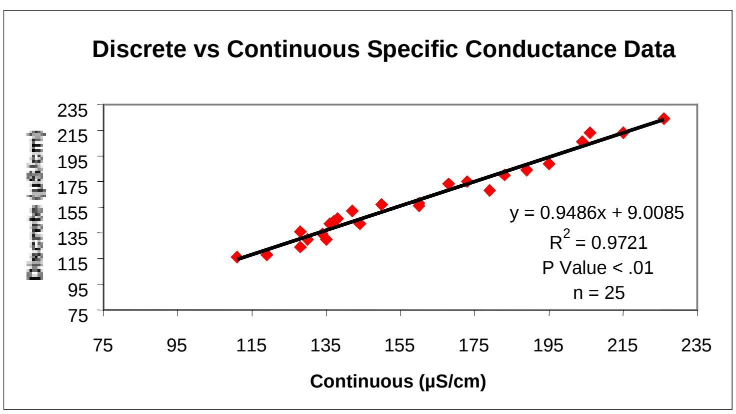






Continuous

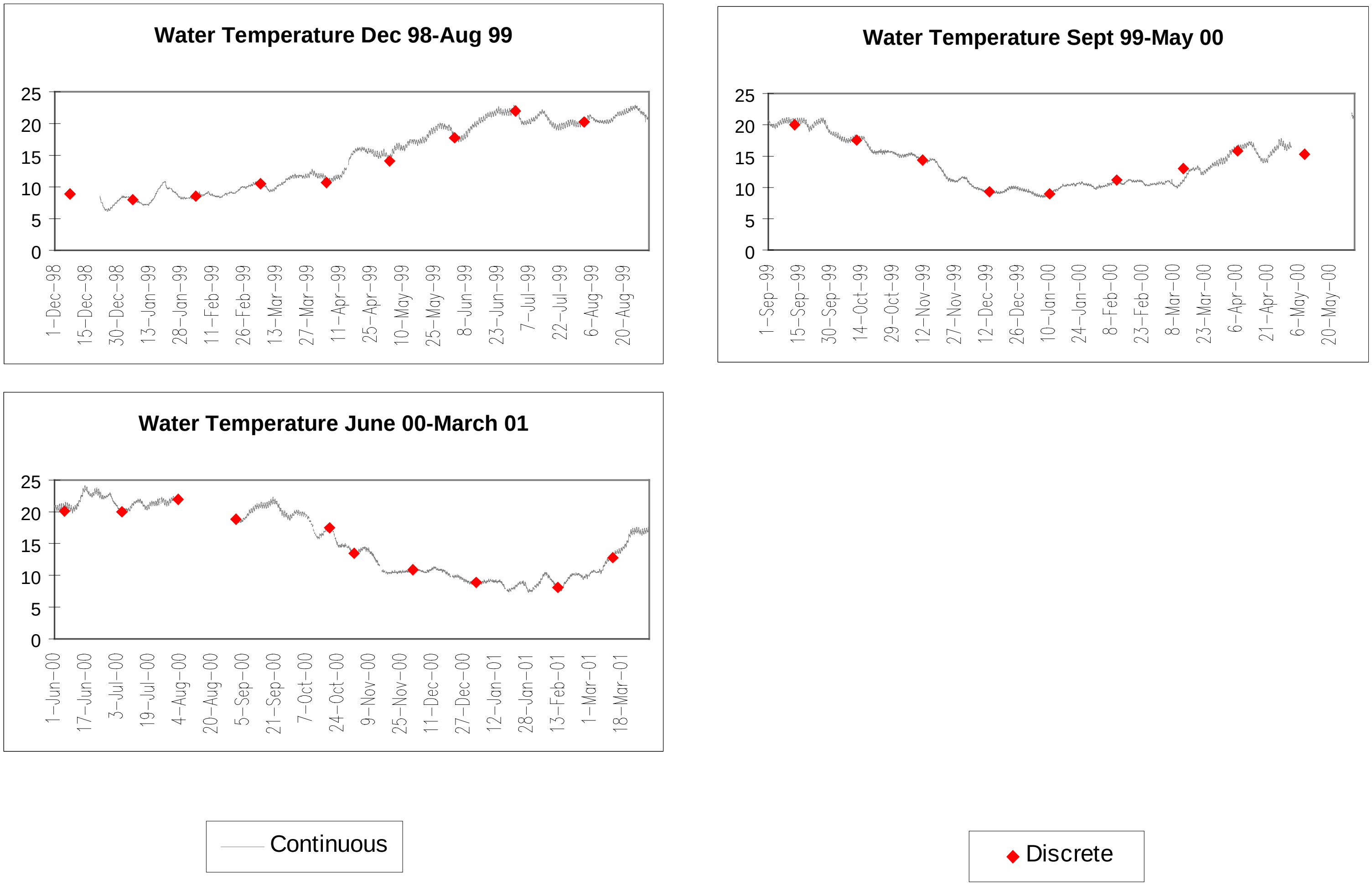
Discrete

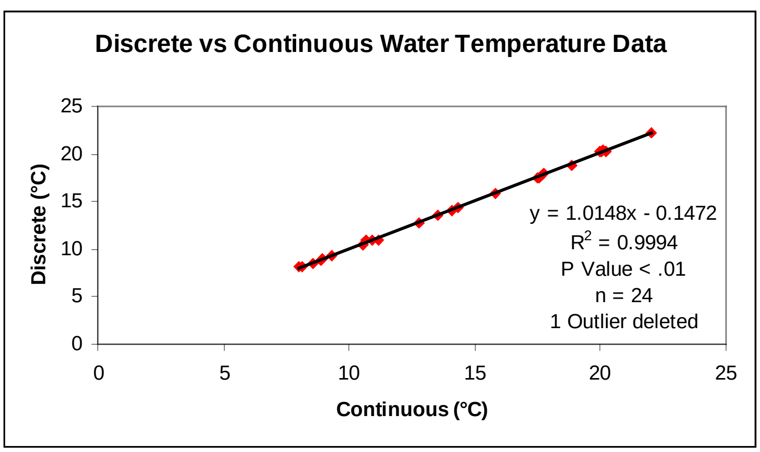


Absolute Difference Discrete - Continuous	
Mean	-0.8
Standard Deviation	5.5
Minimum	-10
Maximum	11

Residuals	
Standard Deviation	5.4
Minimum	-9
Maximum	11.6

Water Temperature (°C) for Discrete Station C3 and Continuous Monitoring Station 70
December 1998 – March 2001

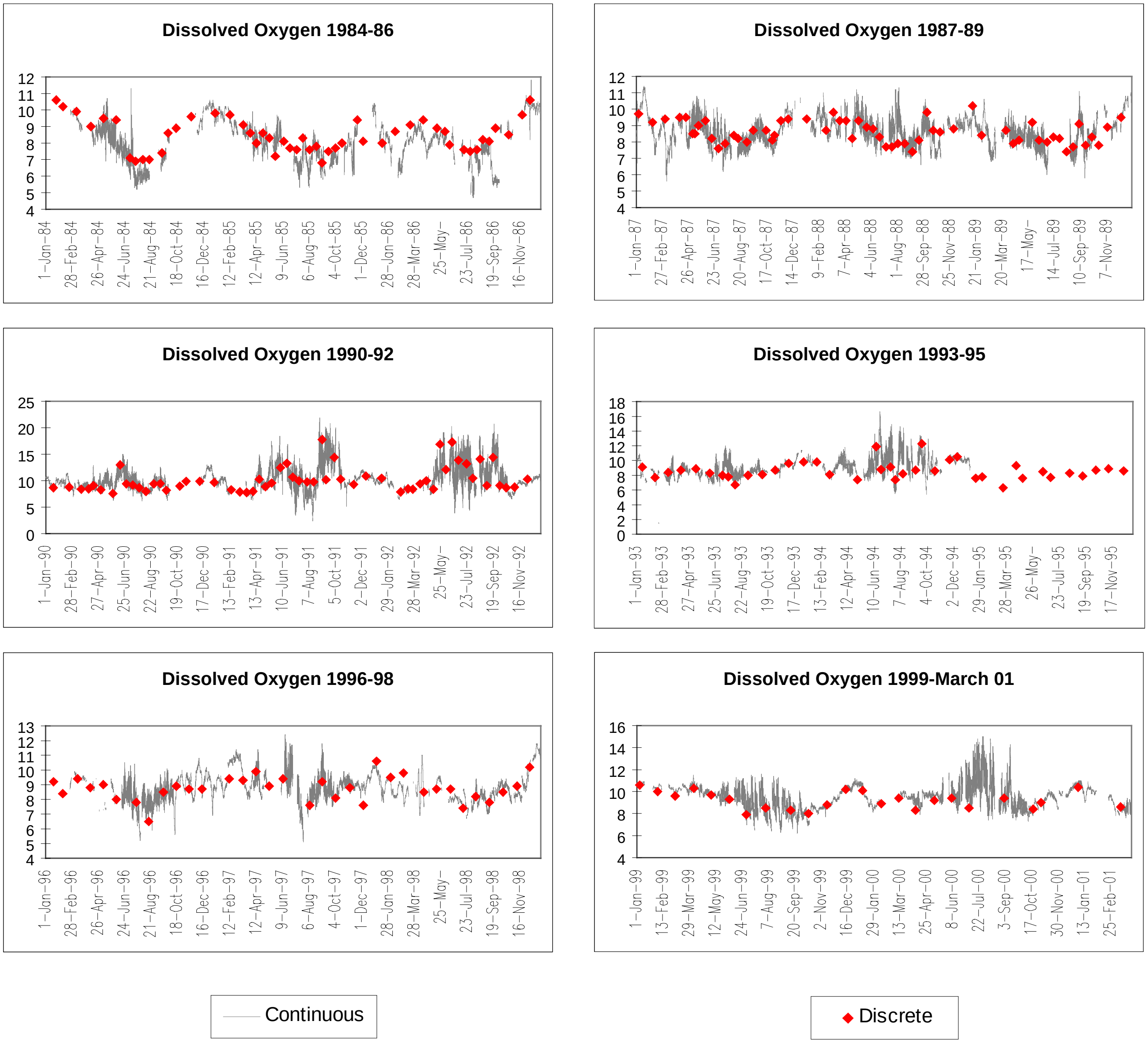


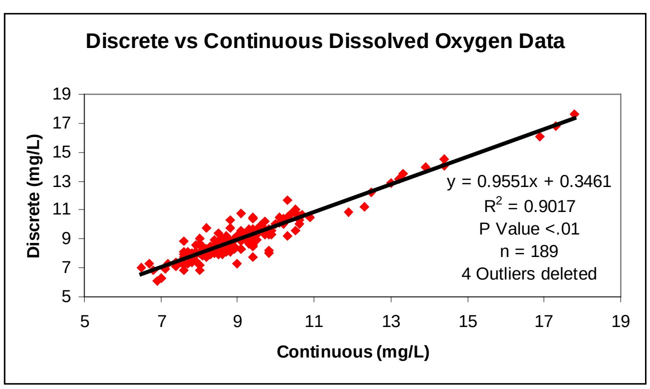


Absolute Difference Discrete - Continuous	
Mean	-0.06
Standard Deviation	0.13
Minimum	-0.4
Maximum	0.18

Residuals	
Standard Deviation	0.11
Minimum	-0.24
Maximum	0.19

Dissolved Oxygen (mg/L) for Discrete Station C10 and Continuous Monitoring Station 10
1984 – March 2001

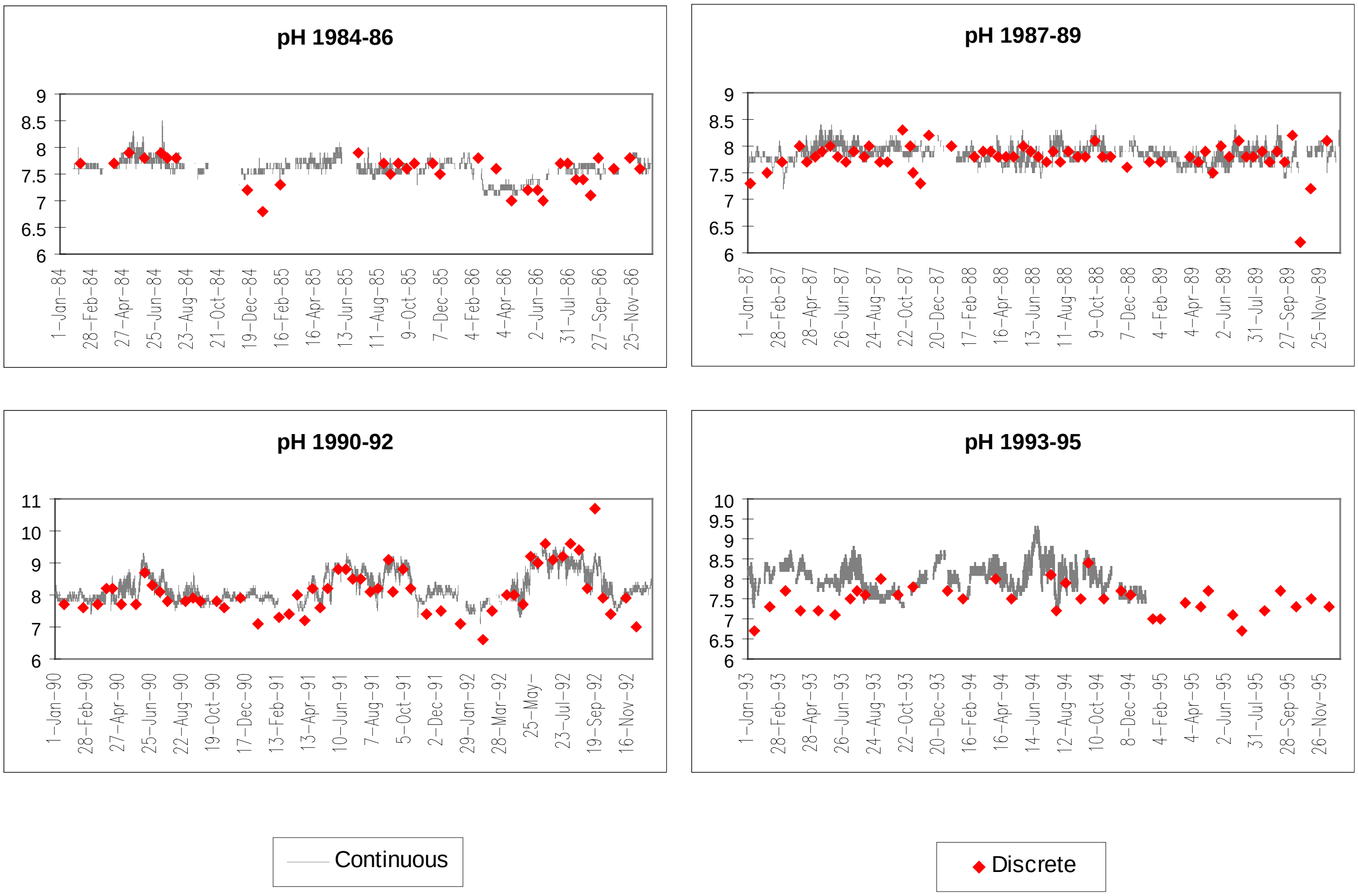


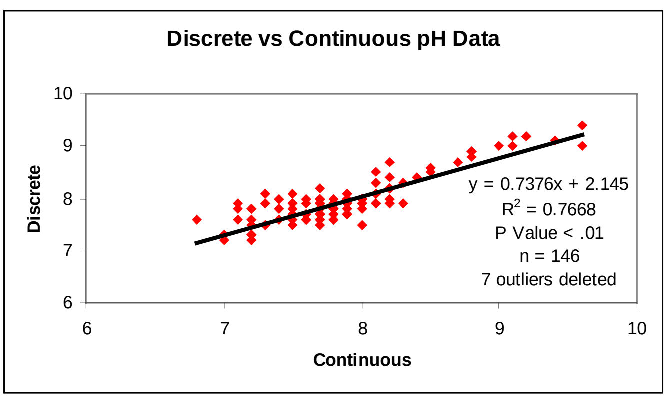


Absolute Difference Discrete - Continuous	
Mean	0.06
Standard Deviation	0.53
Minimum	-1.7
Maximum	1.8

Residuals	
Standard Deviation	0.53
Minimum	-1.66
Maximum	1.68

pH for Discrete Station C10 and Continuous Monitoring Station 10
1984 – 1995



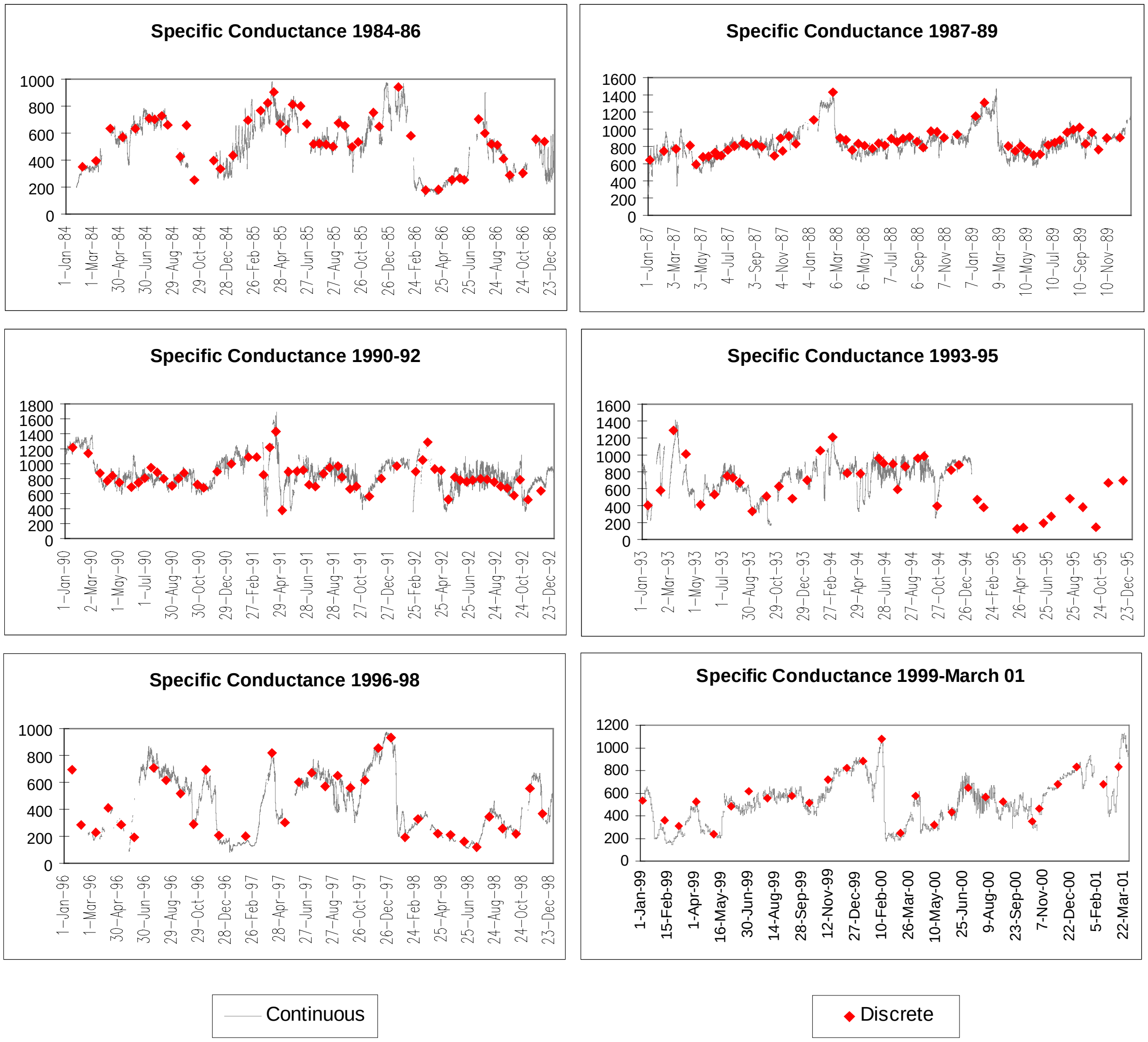


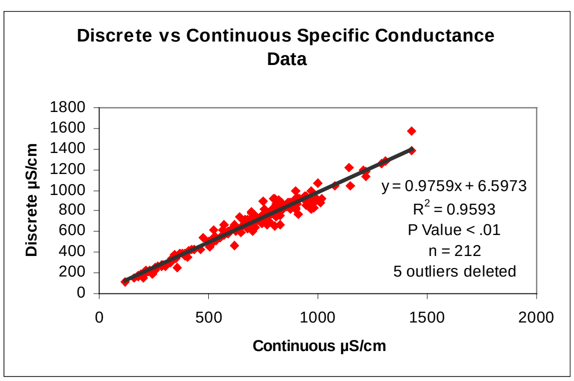
Absolute Difference Discrete - Continuous	
Mean	-0.08
Standard Deviation	0.23
Minimum	-0.8
Maximum	0.6

Residuals	
Standard Deviation	0.23
Minimum	-0.72
Maximum	0.64

Specific Conductance (µS/cm) for Discrete Station C10 and Continuous Monitoring Station 10

1984 – March 2001





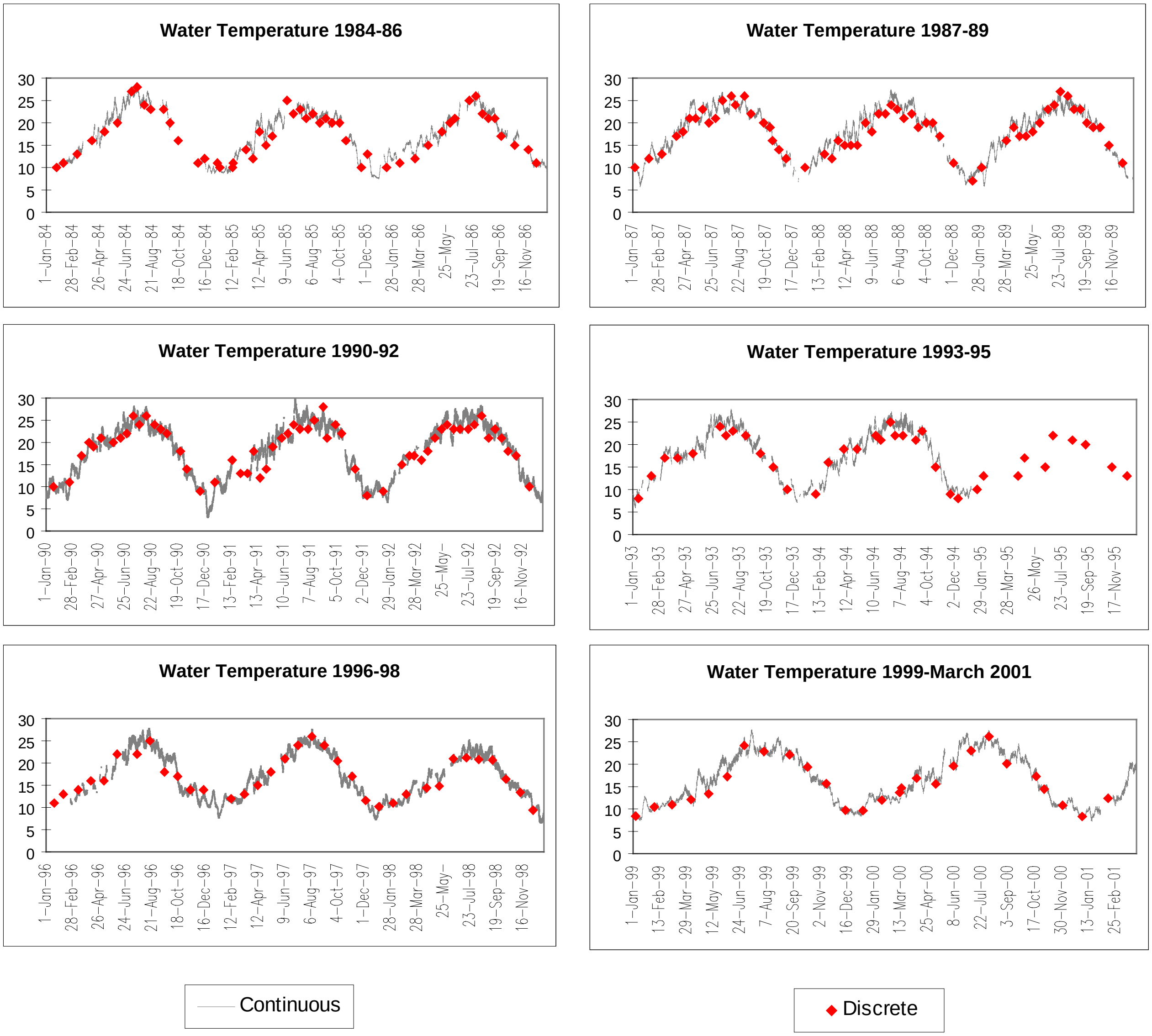
Absolute Difference Discrete - Continuous	
Mean	10.1
Standard Deviation	50.5
Minimum	-149.0
Maximum	165.0

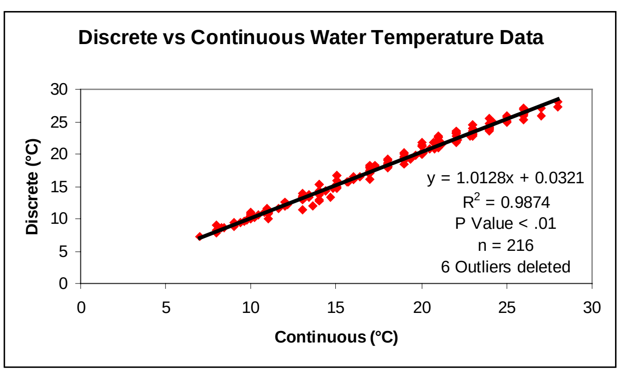
Residuals	
Standard Deviation	50.3
Minimum	-155.4
Maximum	154.6

B6

Water Temperature (°C) for Discrete Station C10 and Continuous Monitoring Station 10

1984 – March 2001

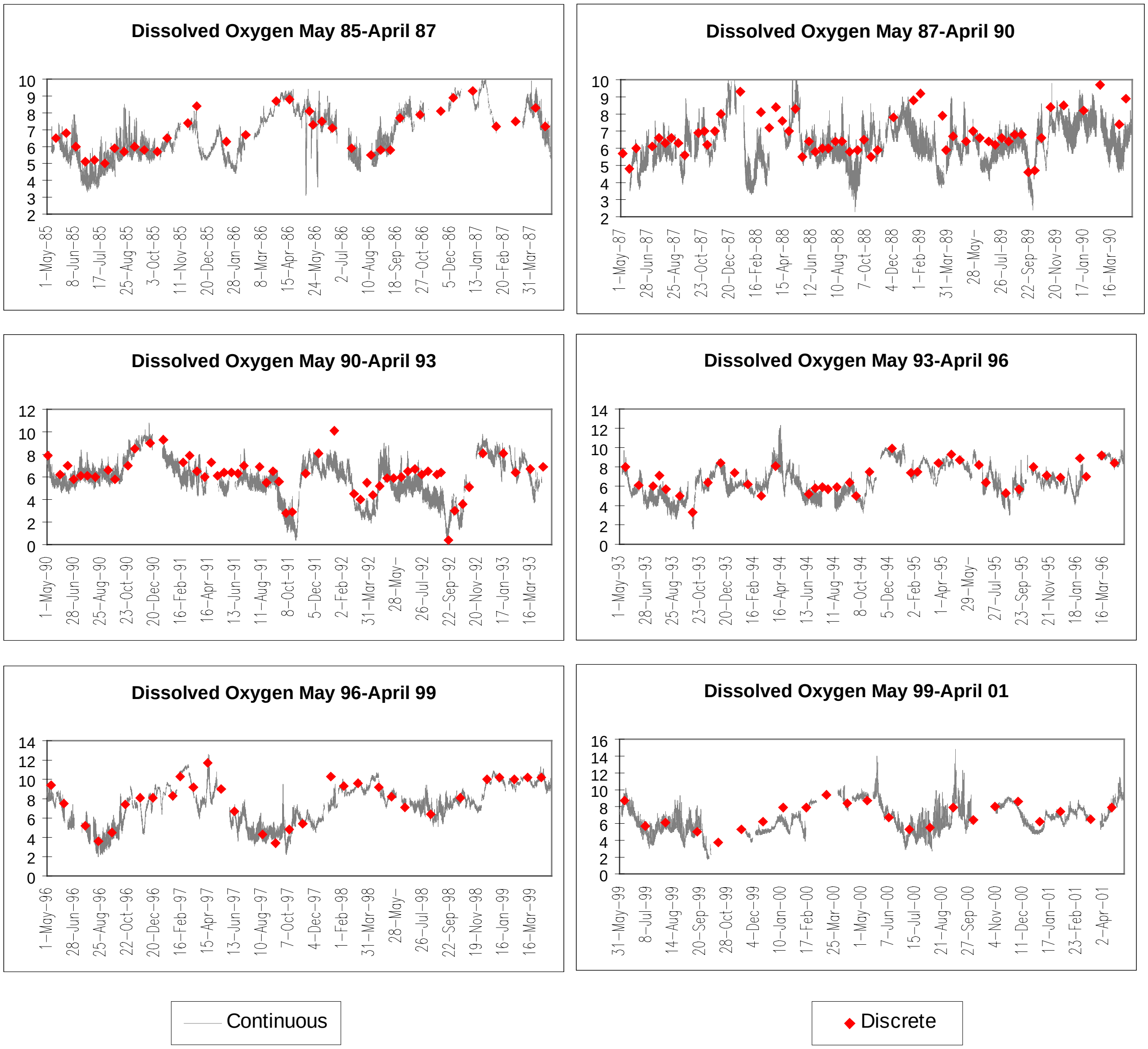


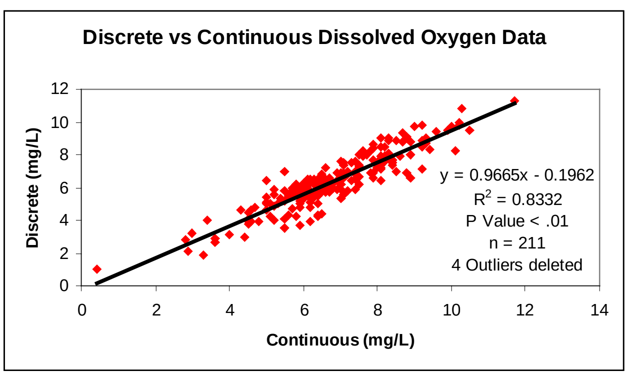


Absolute Difference Discrete - Continuous	
Mean	-0.3
Standard Deviation	0.6
Minimum	-1.7
Maximum	1.7

Residuals	
Standard Deviation	1.0
Minimum	-2.4
Maximum	3.1

Dissolved Oxygen (mg/L) for Discrete Station P8 and Continuous Monitoring Station 20
May 1985 - April 2001





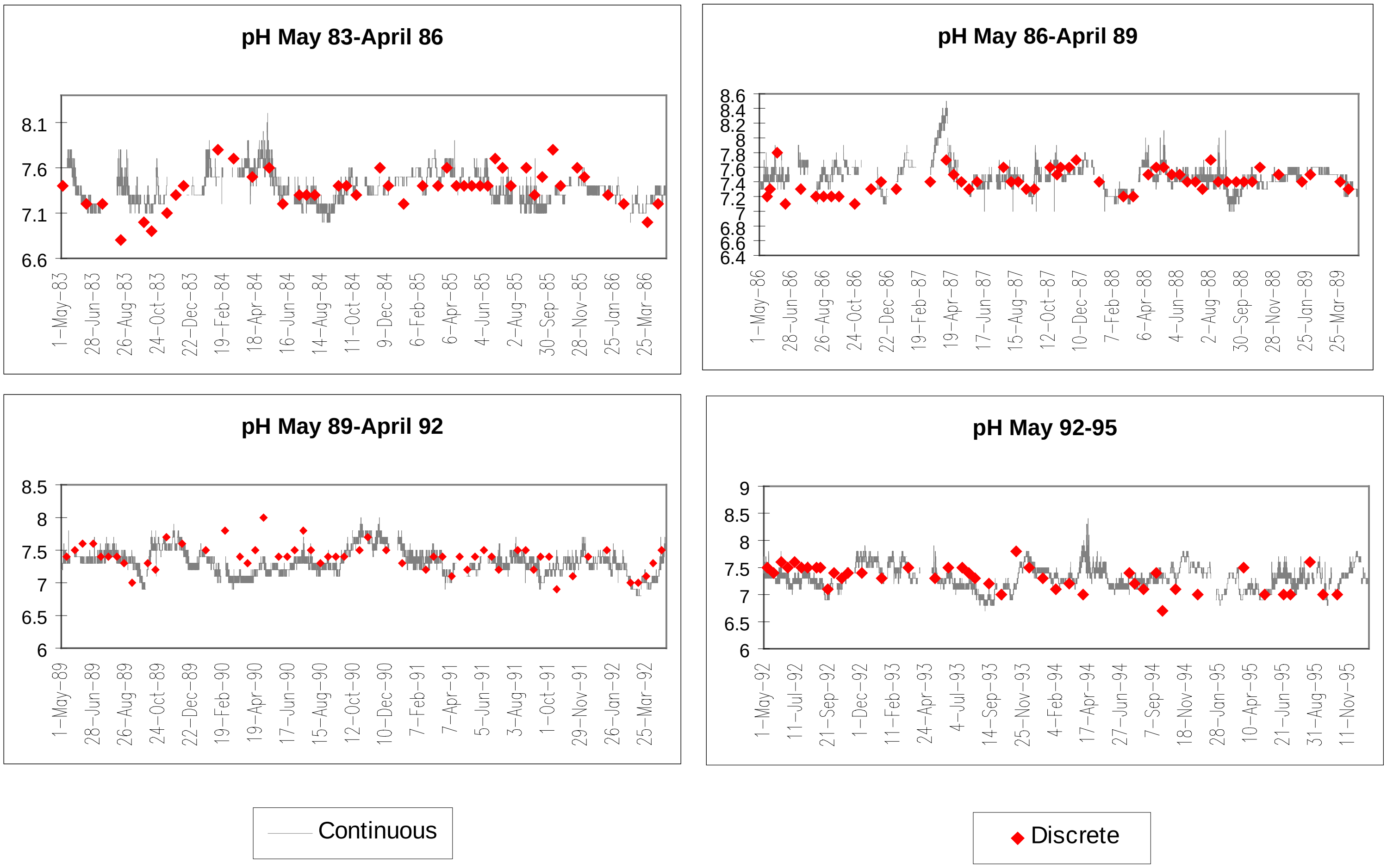
Absolute Difference Discrete - Continuous	
Mean	0.42
Standard Deviation	0.7
Minimum	-1.5
Maximum	2.3

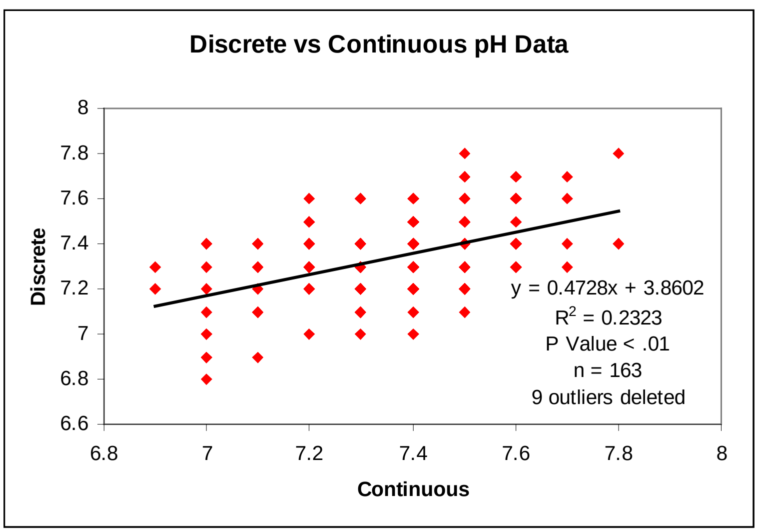
Residuals	
Standard Deviation	0.66
Minimum	-1.84
Maximum	1.90

B8

pH for Discrete Station P8 and Continuous Monitoring Station 20

May 1983 – 1995

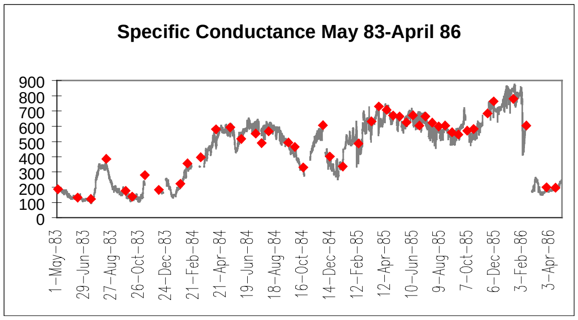


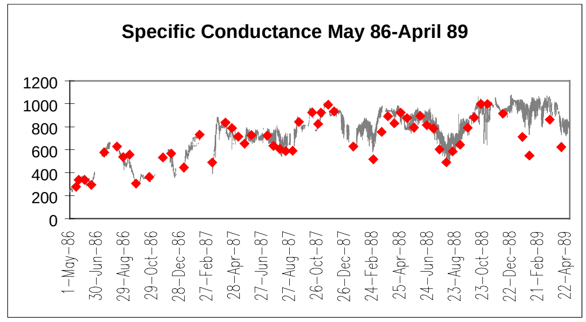


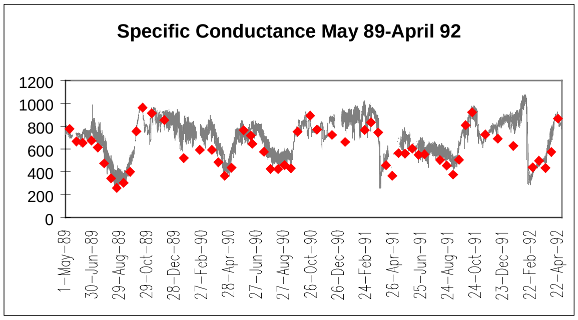
Absolute Difference Discrete - Continuous	
Mean	0.03
Standard Deviation	0.18
Minimum	-0.40
Maximum	0.40

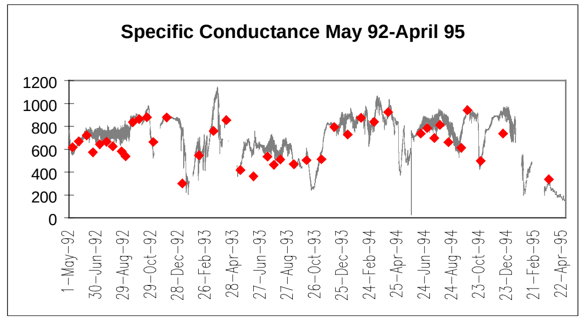
Residuals	
Standard Deviation	0.16
Minimum	-0.45
Maximum	0.40

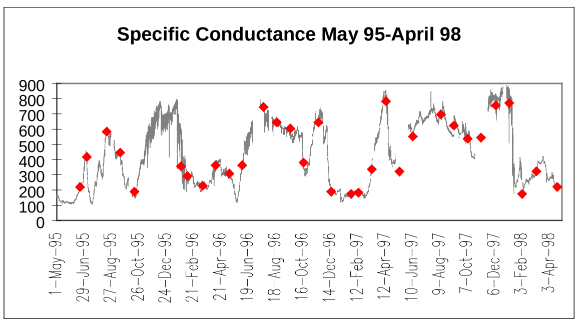
Specific Conductance (µS/cm) for Discrete Station P8 and Continuous Monitoring Station 20 May 1983 - April 2001

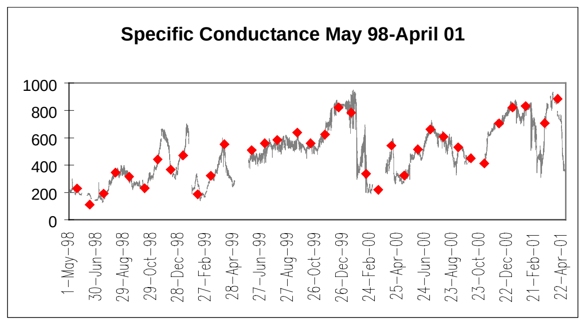






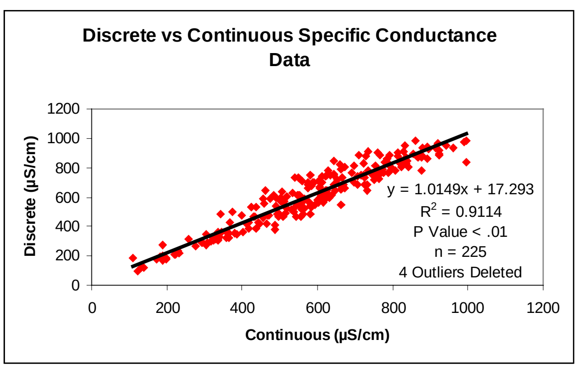






Continuous

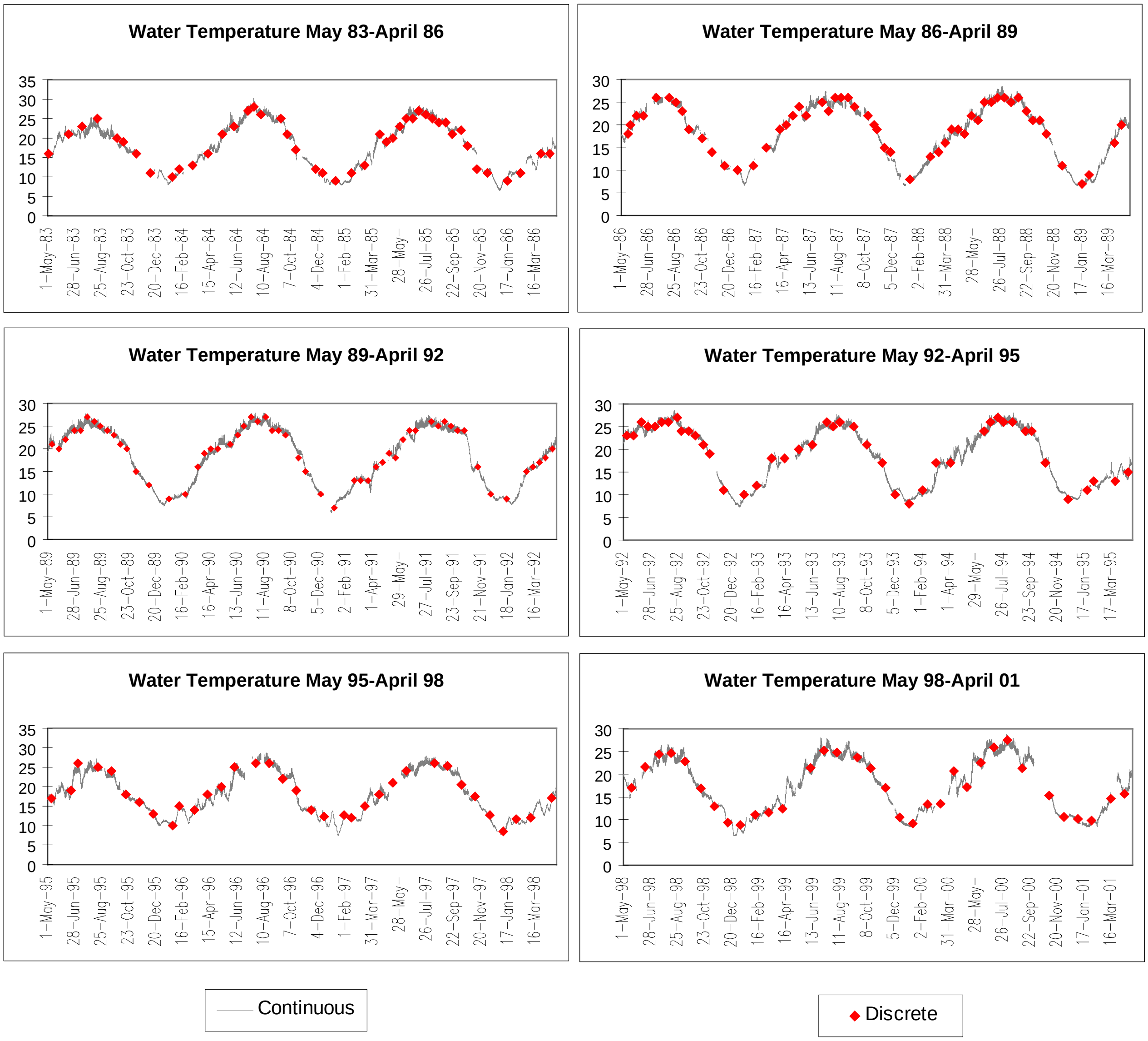
Discrete

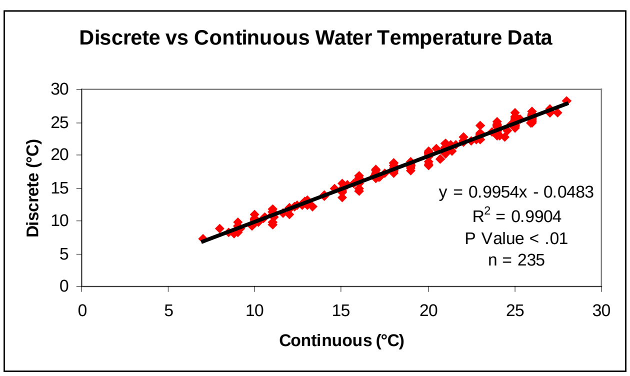


Absolute Difference Discrete - Continuous	
Mean	-26.0
Standard Deviation	65.6
Minimum	-194.0
Maximum	206.0

Residuals	
Standard Deviation	61.6
Minimum	-155.0
Maximum	206.0

Water Temperature for Discrete Station P8 and Continuous Monitoring Station 20 May 1983 - April 2001





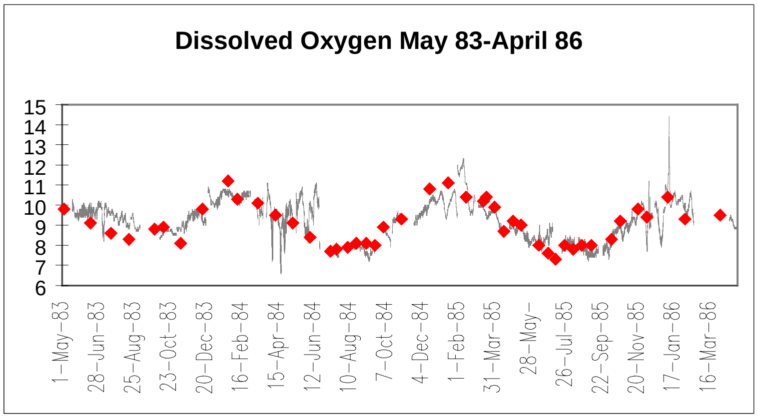
Absolute Difference Discrete - Continuous	
Mean	0.14
Standard Deviation	0.55
Minimum	-1.50
Maximum	1.60

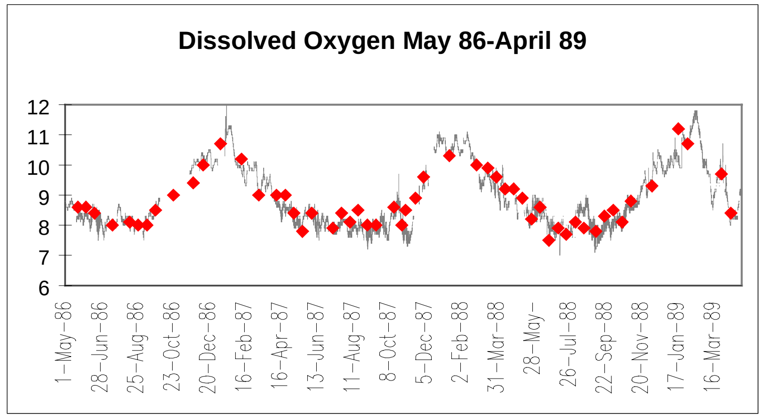
Residuals	
Standard Deviation	0.55
Minimum	-1.61
Maximum	1.48

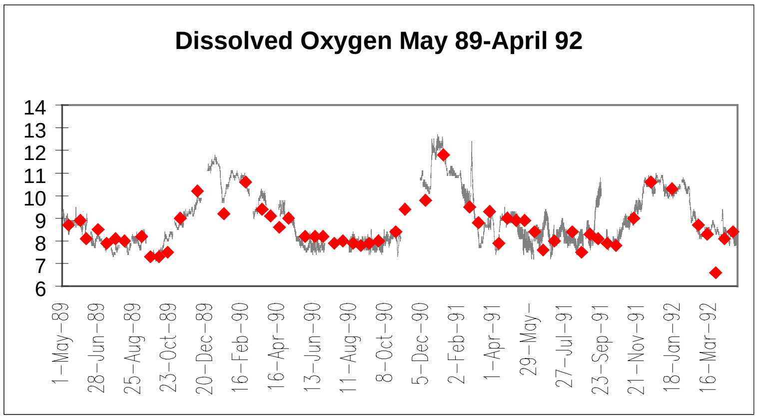
B11

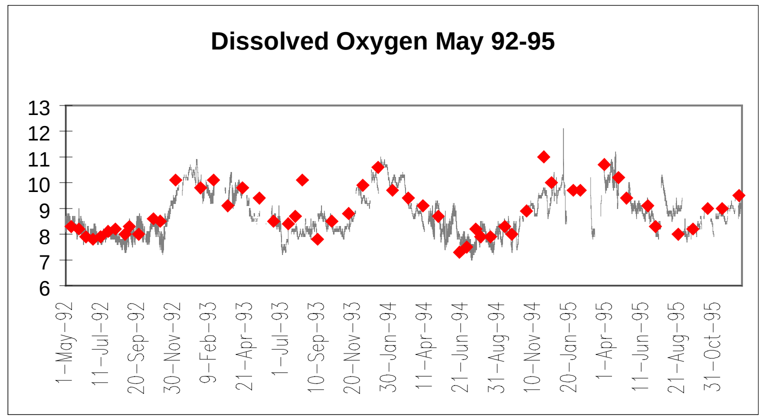
Dissolved Oxygen (mg/L) for Discrete Station D24 and Continuous Monitoring Station 30

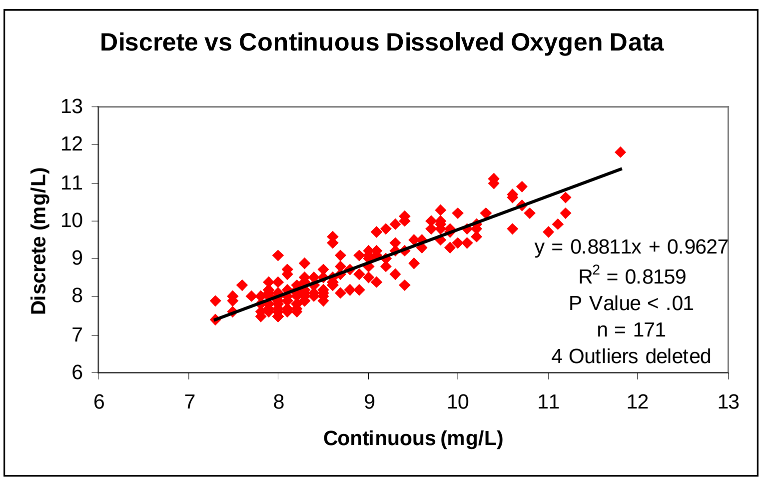
May 1983 – 1995









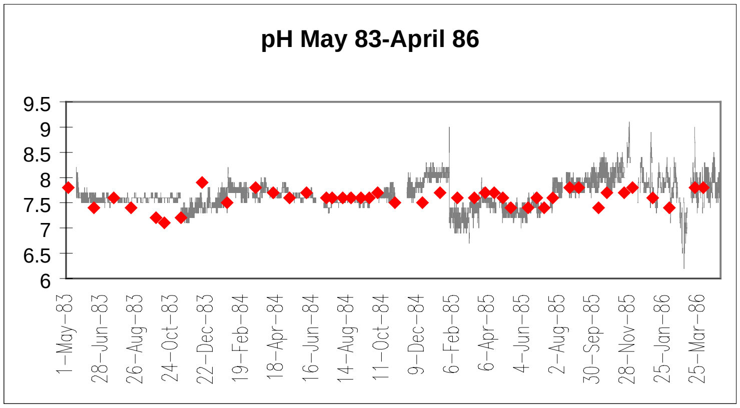


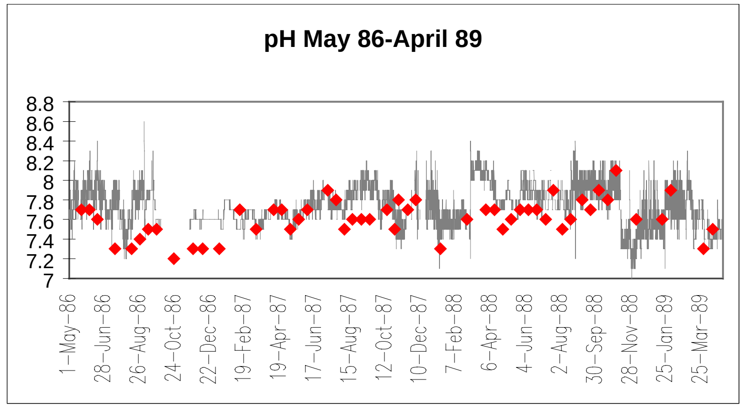
Absolute Difference Discrete - Continuous	
Mean	0.08
Standard Deviation	0.41
Minimum	-1.10
Maximum	1.30

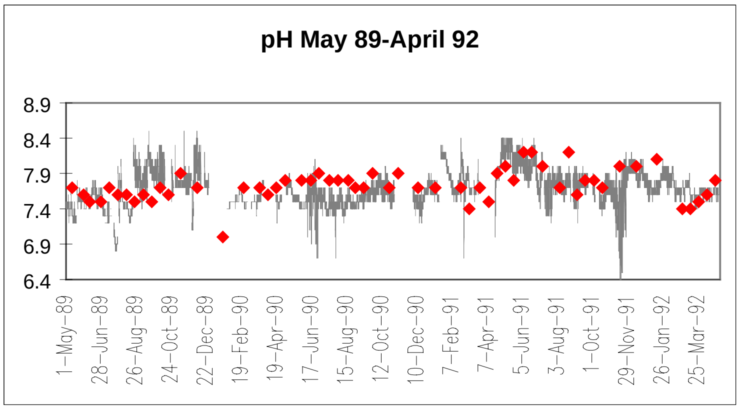
Residuals	
Standard Deviation	0.41
Minimum	-1.15
Maximum	1.29

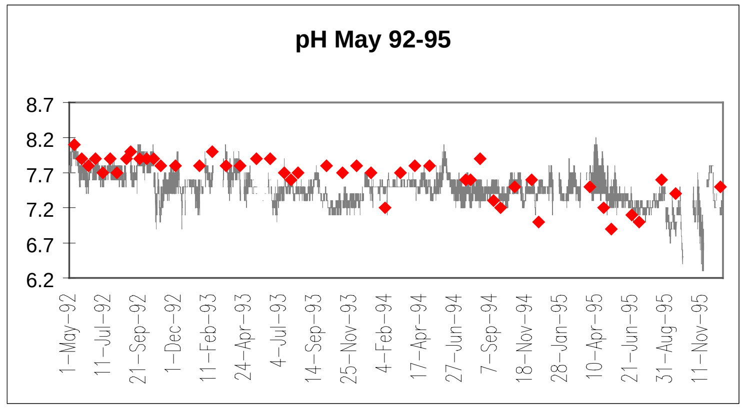
pH for Discrete Station D24 and Continuous Monitoring Station 30

May 1983 – 1995



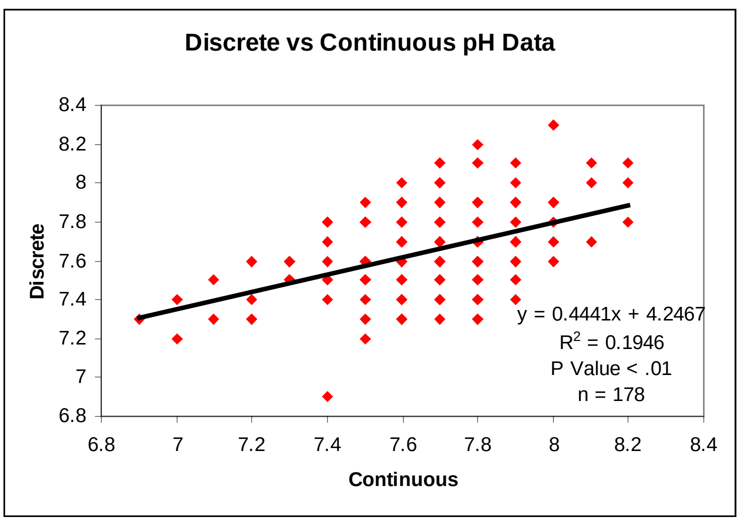






Continuous

Discrete



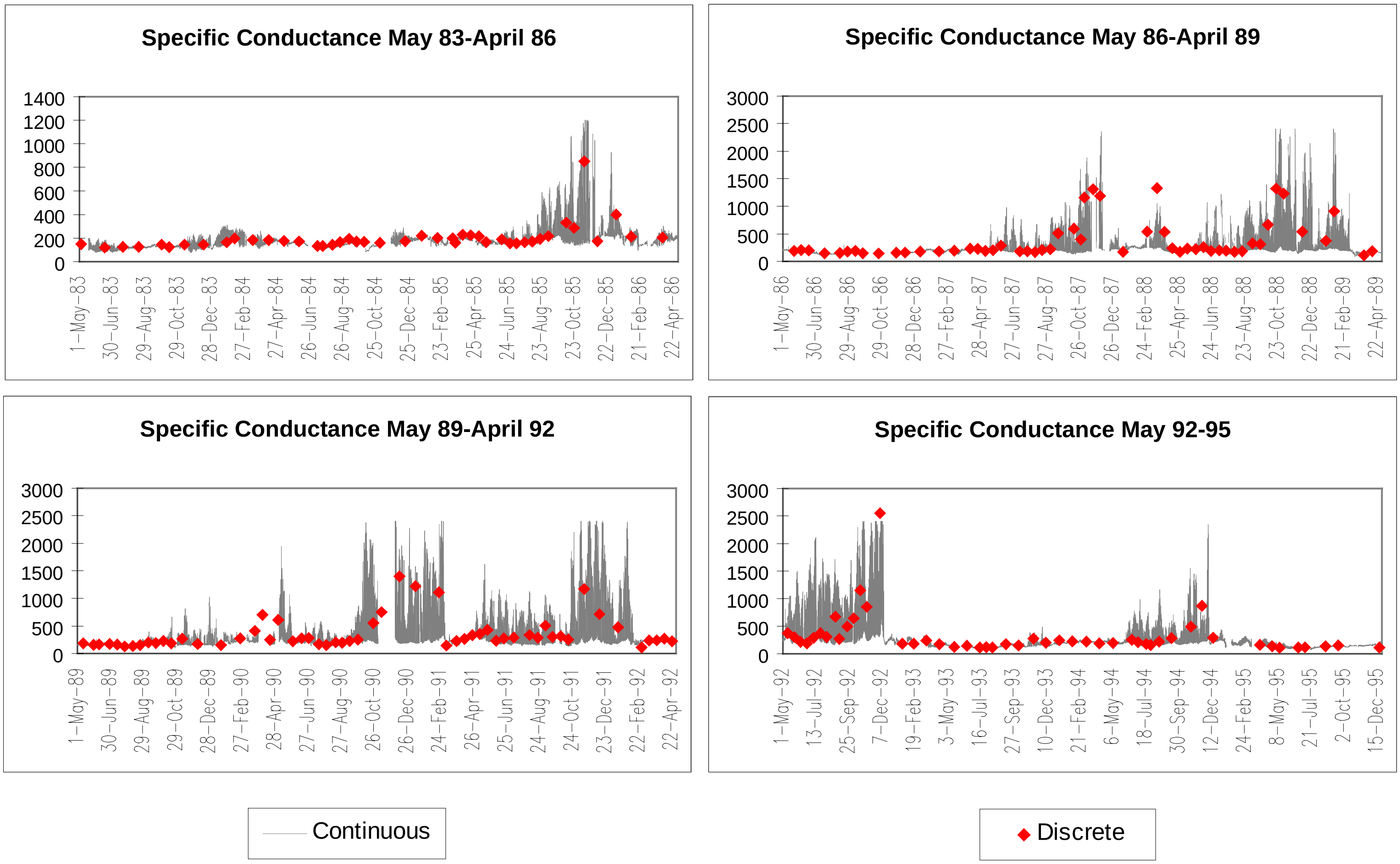
Absolute Difference Discrete - Continuous	
Mean	0.01
Standard Deviation	0.25
Minimum	-0.60
Maximum	0.60

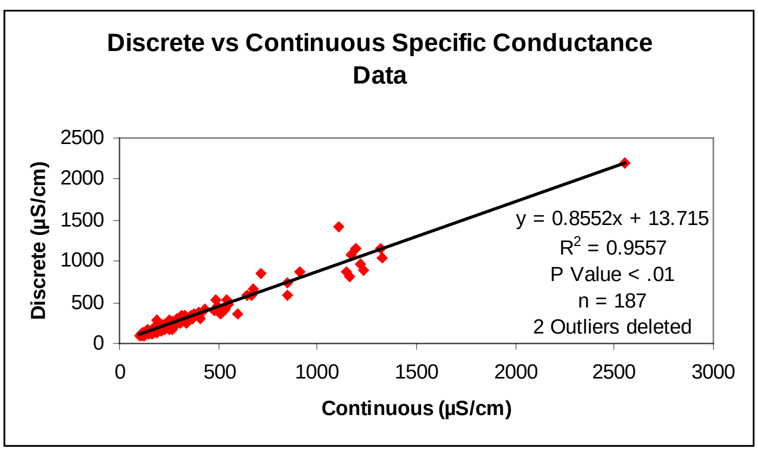
Residuals	
Standard Deviation	0.21
Minimum	-0.62
Maximum	0.49

B13

Specific Conductance (µS/cm) for Discrete Station D24 and Continuous Monitoring Station 30

May 1983 – 1995





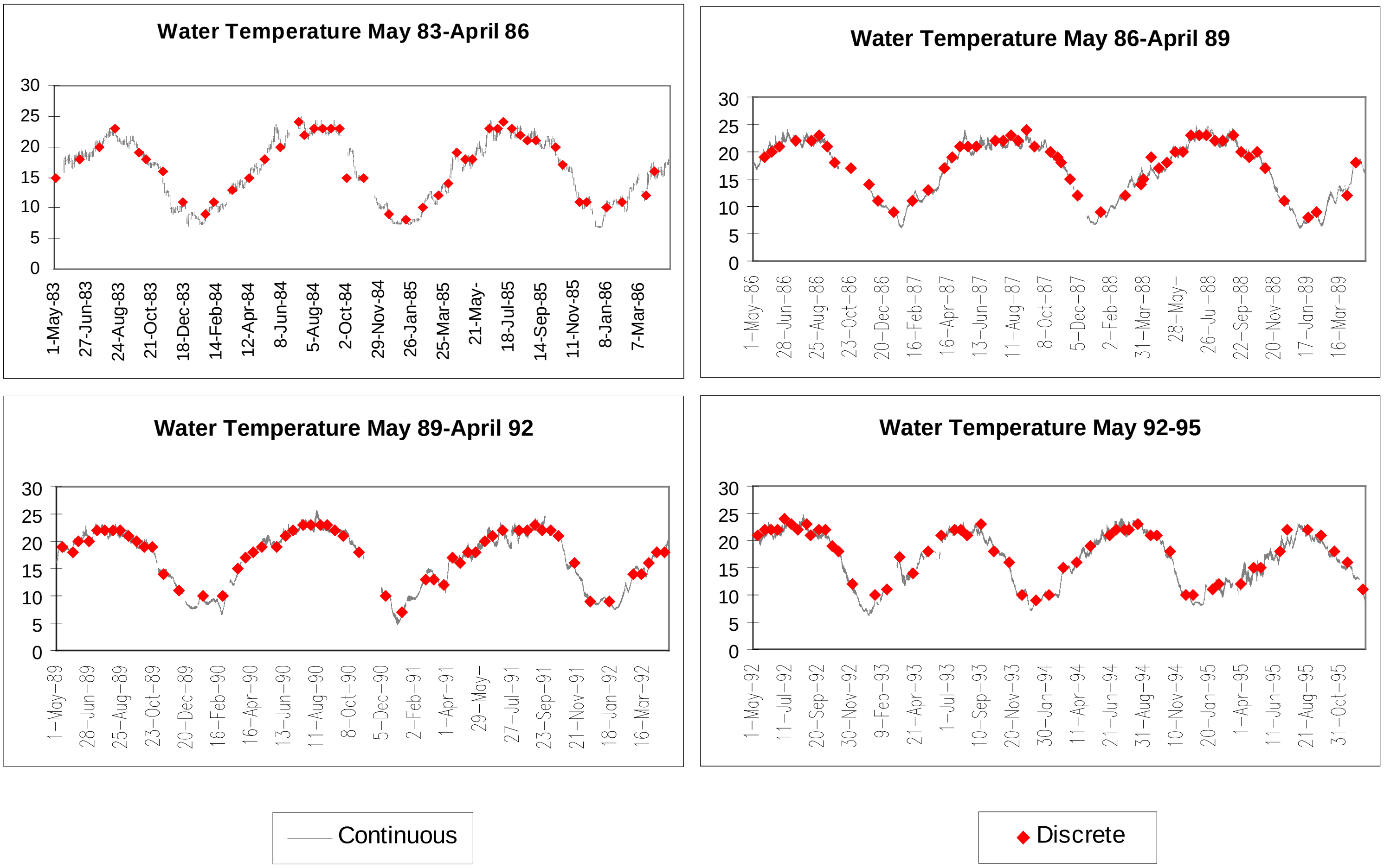
Absolute Difference Discrete - Continuous	
Mean	30.6
Standard Deviation	69.9
Minimum	-315.0
Maximum	352.0

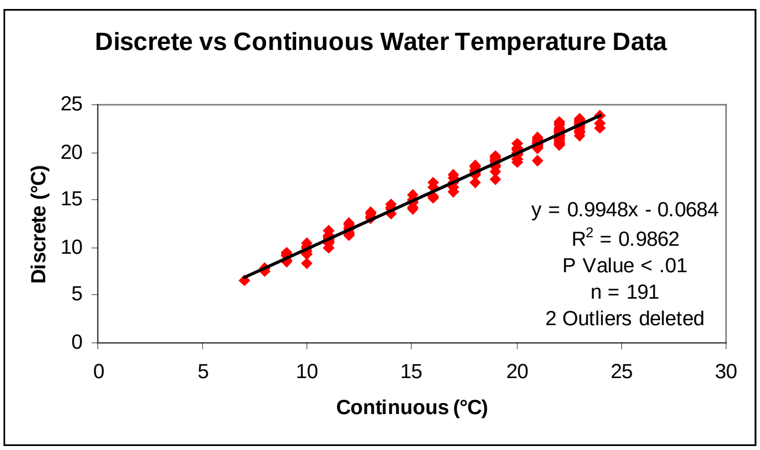
Residuals	
Standard Deviation	62.8
Minimum	-480.8
Maximum	258.8

B14

Water Temperature (°C) for Discrete Station D24 and Continuous Monitoring Station 30

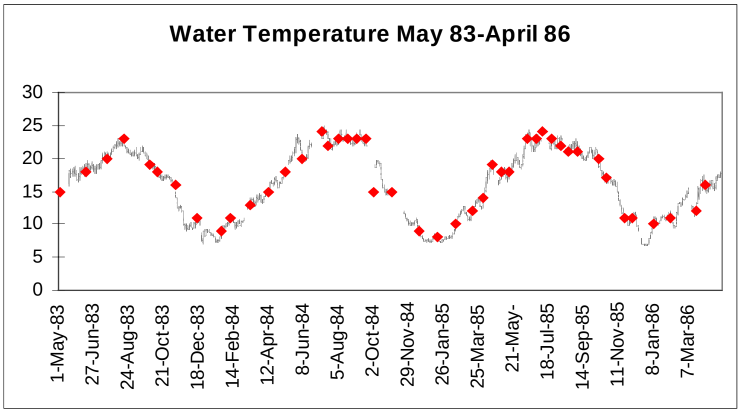
May 1983 – 1995

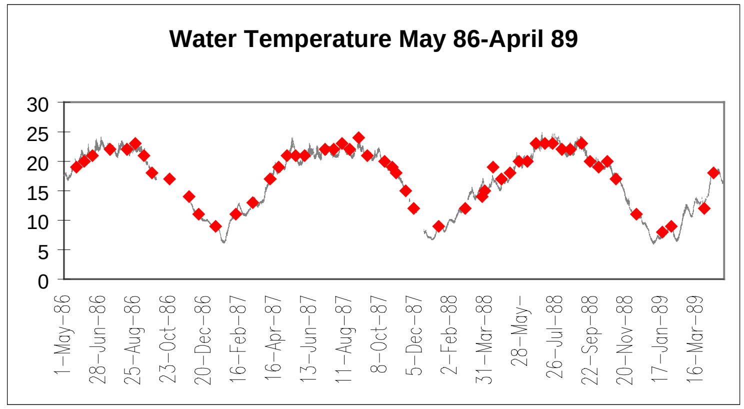


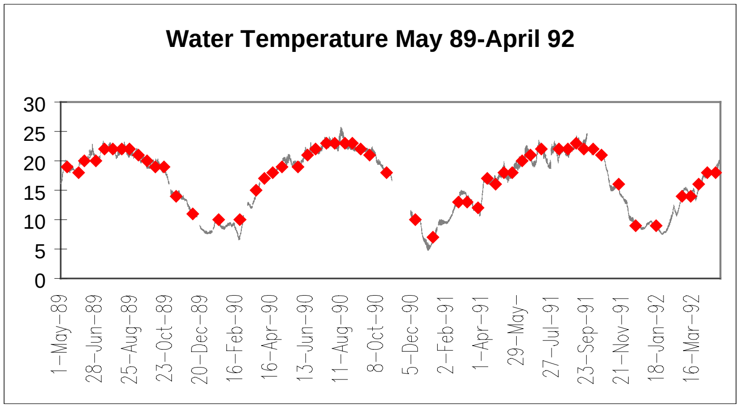


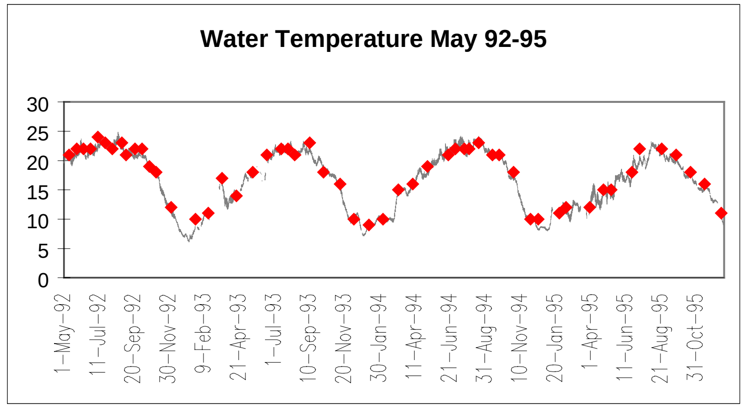
Absolute Difference Discrete - Continuous	
Mean	0.16
Standard Deviation	0.55
Minimum	-1.20
Maximum	1.90

Residuals	
Standard Deviation	0.55
Minimum	-1.31
Maximum	1.75



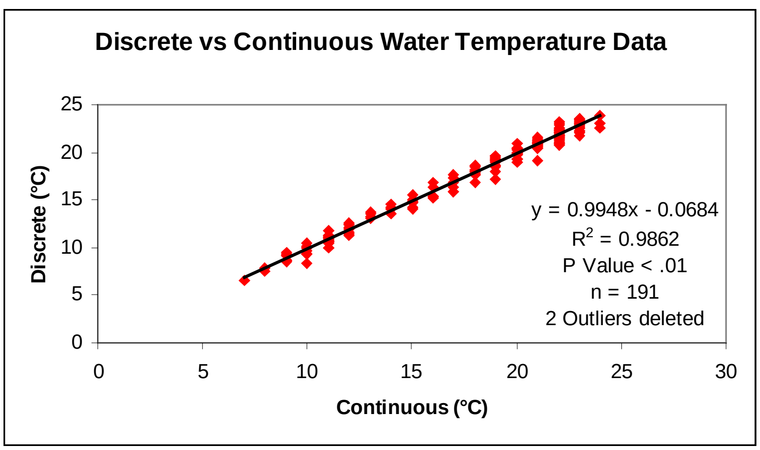






Continuous

Discrete



Absolute Difference Discrete - Continuous	
Mean	0.16
Standard Deviation	0.55
Minimum	-1.20
Maximum	1.90

Residuals	
Standard Deviation	0.55
Minimum	-1.31
Maximum	1.75

Appendix C

Details on water quality variables monitored as part of the recommended EMP[10]

Physical variables

Meteorological measures: These include wind speed and direction, air temperature, relative humidity, precipitation, and sunlight, used in measuring and modeling of water circulation and mixing, primary productivity, and suspended sediment transport.

Salinity: This is a critical feature of the upper estuary, useful as a tracer of water mixing, and is used in a standard that is achieved by controlling freshwater flow. Shipboard monitoring of salinity and other variables is done with CTD's, which have become standard equipment for bay sampling. CTD profiles at shipboard sampling stations are generally used to provide a context for biological measurements, whereas continuous monitoring at fixed stations is used to provide information on the state of the physical system. Salinity is a computed variable. The measured variables are specific conductance (uncorrected for temperature) and the ambient temperature. When hydrostatic pressure is not an issue, salinity can be computed from these two variables, although it is good practice to report the measured variables as well as the computed variables. There is some confusion among scientists and engineers working in the San Francisco Estuary regarding the methods and units for reporting salinity. However, the details are clear in the literature (Schemel, 2000). The Practical Salinity Scale (PSS) is useful up to the point where salt composition becomes an issue. It is also possible to extend the scale to deal with low specific conductance values (Schemel, 2000 and references within); however PSS values < 0.2 are more appropriately reported as specific conductance.

Water Temperature: This is also a critical habitat feature for all aquatic species because it regulates chemical and metabolic processes. Shipboard and *in situ* measurement should be as for salinity.

Suspended sediments: This provides a measure of the sediment load moving through the Bay-delta system and is a controlling factor for water column primary productivity. As with salinity and temperature, a combination of shipboard and continuous sampling is necessary; however, sediment data are more difficult to interpret because sediments are highly non-conservative.

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[10] Much of the information presented in Appendix I is taken from the following CMARP technical appendix: *Estuarine System Productivity: Lower Trophic Levels*. Kimmerer, W., F. Nichols, P. Lehman, B. Cole, B. Thompson, and E. Cummings. Revised draft October 23, 1998. The full appendix is available at http://www.iep.ca.gov/cmarp/groups/toc.html

Generally these measurements are made with OBS (optical backscatter) instruments included with CTD instrument packages. Discrete samples for determination of total suspended solids, volatile suspended solids, dissolved solids, and turbidity (NTU) should also be collected to preserve continuity with the historical data base, to provide a better understanding of the components responsible for changes in optical backscatter measurements, and as a means of quality control.

Water clarity/Light attenuation: A measure of light availability for support of primary productivity, this should be monitored in routine shipboard sampling and can be derived from OBS sensors. However, Secchi disk readings should be continued for calibration with the historical database.

Flow Variables: These provide the essential underlying information defining the hydrologic environment of the Bay-delta and thus for interpreting and analyzing data from the estuary, in particular within the delta. Efforts to unite high frequency flow measurements with other water quality data collected at high frequency should be continued and where appropriate enhanced. The ability to calculate constituent loads is of increasing importance to the conservation and management of the estuary.

Total daily inflow: Data should be provided from all tributary rivers and the Yolo Bypass.

Diversion flows: This should include export flow at the state and federal water projects, as well as flows at agricultural diversions within the delta, including actual measures of gross removal and return flows.

Tidal flows: Data on tidal stage and velocity at various locations is essential for relating results of sampling runs to potential tidal influences.

Net (tidally-averaged) flows: Flows at selected nodes are extremely useful for calibrating models and for understanding the movements of fish and substances. Flows within the delta should be determined routinely, e.g., intake channel from Old River into Clifton Court Forebay, Grant Line Canal, Turner Cut, Columbia Cut or Middle River south of Columbia Cut, Connection Slough, and the San Joaquin River near Mandeville Island. In addition, techniques should be developed for measuring net flow rates at sites seaward of the delta, e.g., at the confluence of the Sacramento and San Joaquin Rivers, at Chipps Island, Montezuma Slough, New York Slough, Carquinez Strait, and the Golden Gate. Additional sites should be selected that would be relevant to the CALFED alternatives for structural changes in the delta flow regime

Chemical variables

pH: This variable is routinely measured in studies of freshwater environments, as it can be diagnostic of acidification problems. Abrupt changes in pH in the delta (freshwater regions) can be indicative of phytoplankton blooms. It is not very useful in marine or brackish systems (except that it is necessary in primary productivity measurements), or when there is not a problem with acid-base chemistry. This variable should be monitored on a routine basis during other routine sampling in freshwater only.

Dissolved Oxygen: Low dissolved-oxygen concentrations can affect the health of aquatic organisms and impede migration of fish. Low dissolved oxygen concentrations are a good indicator of eutrophication, a common condition in estuaries in which high nutrient loading produces excess respiration following phytoplankton growth. Although eutrophication has not been a problem in this estuary, low dissolved oxygen concentrations are routinely measured in the Stockton Ship Channel in the summer and fall, where high amounts of effluent, storm water runoff, redox reactions, phytoplankton biomass, and water temperature combine with low streamflow. If the estuary continues to become clearer, problems of eutrophication and hypoxia may increase as phytoplankton production increases. This, combined with the low cost of these measurements, suggests discrete measurement should continue with continuous monitoring at fixed stations in the San Joaquin River. Data should be reported both as concentration and percent of the saturated value for the temperature.

Nutrients: The "macronutrients" required for growth by the phytoplankton and submerged aquatic vegetation comprise several forms of nitrogen (nitrate, NO_3^-; nitrite, NO_2^-, and ammonium, NH_4^+), phosphate ($PO_4^{\equiv}$) and silicate. Additional trace nutrients commonly measured in oceanographic sampling (e.g., iron) are probably present in the estuary at high concentrations relative to the requirements of plants. Nutrients apparently become limiting only during blooms, so nutrient concentrations are not very informative. Nevertheless, because they are important indicators of growth conditions for plants, nutrients should be measured during routine discrete sampling cruises.